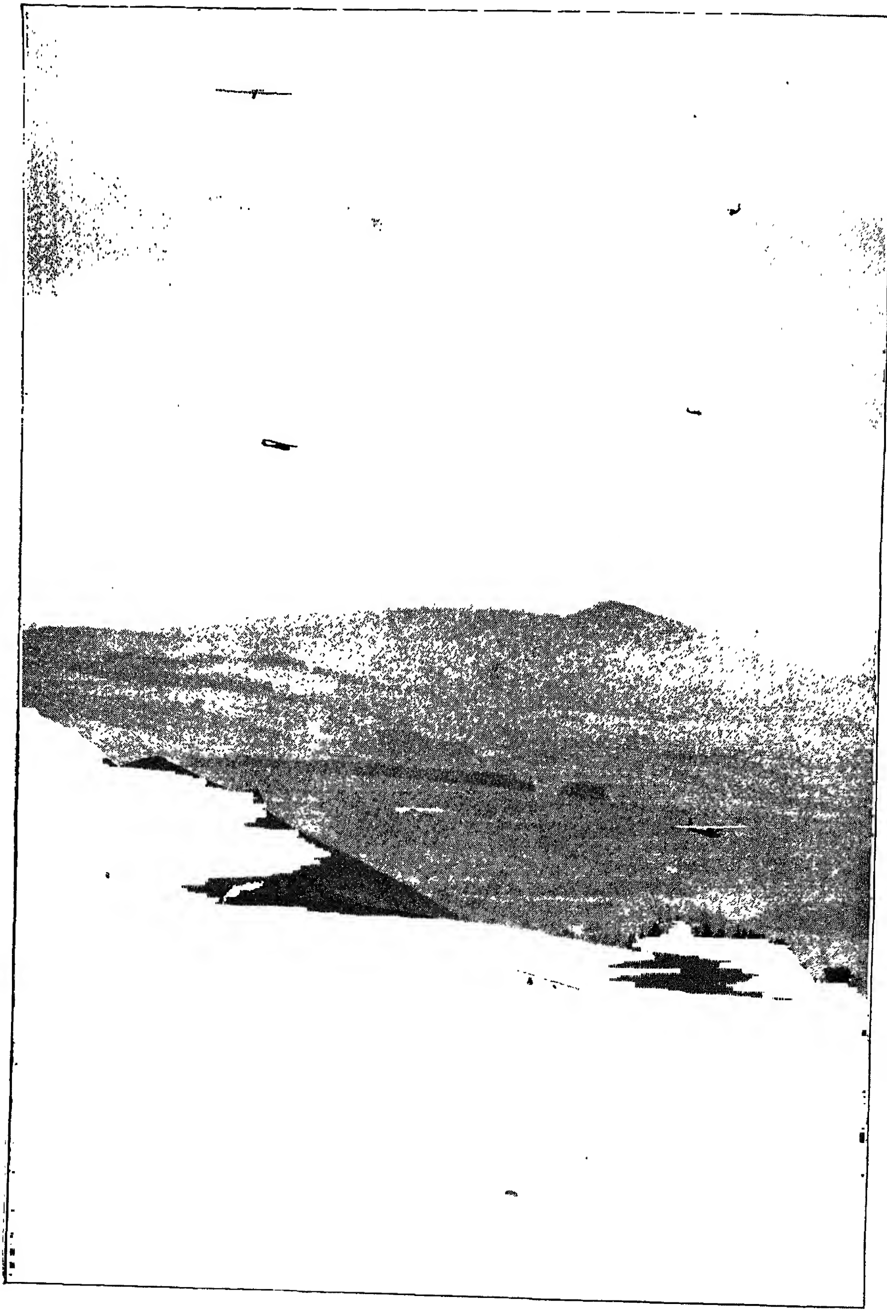
SAILPLANES



SAILPLANES IN FLIGHT.
(*Flugsport*)

[*Frontispiece.*

SAILPLANES

THEIR DESIGN, CONSTRUCTION AND PILOTAGE

By

C. H. LATIMER NEEDHAM

M.Sc. (Eng.) Lond., F.R.Ae.S.

Diploma of Engineering, University College, London University;
Founder Member and Member of Council, British Gliding Association;
Chairman of Technical Committee, British Gliding Association;
Holder of First "C," Soaring, Pilot's Certificate in Great Britain;
Member of Scientific and Technical Committees of the
International Commission for Motorless Flight

With a Foreword by

THE MASTER OF SEMPILL

A.F.C., F.R.Ae.S.

LONDON

CHAPMAN AND HALL, LTD.

11, HENRIETTA STREET, W.C.2

1932

PUBLISHED BY CHAPMAN AND HALL, LTD., II, HENRIETTA STREET, LONDON, W.C. 2
PRINTED IN GREAT BRITAIN BY
THE LONDON AND NORWICH PRESS, LIMITED, ST. GILES WORKS, NORWICH,
AND BOUND BY A. W. BAIN AND CO., LTD., LONDON

To

My Brother,

the Late

Lieut. J. W. D. NEEDHAM, R.F.C.

(48 Squadron),

KILLED IN ACTION, WHILST FLYING, NOVEMBER, 1917, WHO FIRST INTRODUCED ME TO THE SCIENCE OF AVIATION

FOREWORD

By THE MASTER OF SEMPILL, A.F.C., F.R.Ae.S.,

Vice-President, British Gliding Association, Immediate Past President, Royal Aeronautical Society.

The Author of this book was one of the first to become actively associated with motorless flying when interest in the movement was revived in 1929, and was the first Englishman to obtain the " C," soaring pilot's, certificate. By 1930, at the period during which the remarkable demonstrations were being given by the famous Austrian pilot, Herr Kronfeld, the Author was not only closely concerned with the whole of the practical side of flying gliders and sailplanes, and giving instruction to others interested, but also was making experimental flights with a sailplane that had been constructed to his own designs.

It is desirable that these points should be appreciated before the book is perused in order that those who are not familiar with the movement may realise that the author is a person of authority with a record of solid achievement and experience at the back of him.

Gliding and soaring provide for the first time an opportunity for the majority to come into practical contact with the design, construction and operation of aircraft. There are many who would like to do this but who are not able to, in the ordinary circumstances attendant on power flying, due to economic considerations.

Motorless flying opens up an entirely new vista and, apart from its scientific value from the point of view of the design of aircraft, and for meteorological purposes, it has great sporting possibilities. When it is realised that a flight of nearly 200 miles in a straight line has been made by a sailplane, the potentialities from the sporting aspect may be appreciated.

Air transport is destined to play a very great part in the future of the whole world and especially of the British Empire, interspaced as it is by considerable distances, and anything that serves to facilitate aeronautical co-operation from the scientific, technical and practical standpoints is well worthy of the fullest possible support.

W. SEMPILL.

PREFACE

In presenting this small volume the Author wishes to place on record his full appreciation of the help that has been rendered, not only to this country but to the whole world, by the German gliding organisation and the Rhön-Rossitten Gesellschaft in particular.

Great Britain entered the field of motorless flight in 1929, after Germany had persevered for several years and had brought the science to a high standard, and, although much has already been achieved over here, the position would have been very different if we had had to work unaided from the commencement.

We owe our indebtedness to the kindly manner in which our people have been received at Wasserkuppe and Rossitten, for all the information and data that has been placed at our disposal, and for the help and stimulus resulting from the visits to this country of Dr. Georgii, Principal of the R.R.G.; Herr Kronfeld, holder of several world's records; Herr Lippisch, Chief of the Technical Department, R.R.G.; Herr Stamer, Director and Chief Instructor of the Wasserkuppe Gliding School, and others, all of whom have added to our store the fruits of their expert experience in their various capacities.

There is no other book published, certainly not in English, dealing with the design and construction of sailplanes, so that at present those engaged in the work are bound to fall back on aeroplane practice. The exact relation, and difference between, power aircraft and gliders are not always clearly defined, besides which there are many gaps left unfilled.

This volume is intended to illustrate to the would-be designer, constructor, or pilot of sailplanes the lines along which he should work. Sailplanes constitute a special type of aeroplane and, in dealing with gliders, the author has assumed, on the part of the reader, a certain knowledge of the aeroplane structure and its strength and flight requirements.

The part relating to design, Part I, has been kept as simple as possible and where methods or formulæ, approximate but sufficiently accurate for their purpose, are available, these have been given instead of intricate and more laborious methods. Where more exact information is in existence, references to such works have been indicated. A good general knowledge of mechanics has been assumed for this part.

The Author wishes to acknowledge his indebtedness to Mr. F. J. Sanger, A.C.G.I., D.I.C., B.Sc., for reading of MS., checking calculations and for making helpful suggestions; to the Controller of H.M. Stationery Office for permission to make use of Air Publication 970, together with R. and M.s 928 and 1071; and to the British Gliding Association, the Royal Aeronautical Society and the authors of the *Handbook of Aeronautics* for the use of blocks. Also to Messrs. Smith's Instruments, Ltd., Mr. O. G. Karlowa, of the Askania Instrument Co., Herr Oscar Ursinus, Editor of *Flugsport*, and the various glider manufacturing firms for the use of blocks, photographs, etc.

A first book of this character is bound to cause a certain amount of criticism, and the Author will be indebted to those who kindly draw his attention to any mistakes or omissions.

Finally, if the publication of this volume helps to advance, in some measure, the British gliding movement, then the Author's object will have been achieved.

C. H. LATIMER NEEDHAM.

WENDOVER,
February, 1932.

CONTENTS

PAGE

FOREWORD BY THE MASTER OF SEMPILL, A.F.C., F.R.Ae.S. vii

PREFACE ix

LIST OF SYMBOLS USED xv

INTRODUCTORY xvii

PART I

SAILPLANE DESIGN

CHAPTER I. STRENGTH REQUIREMENTS . . . 3

Strength Requirements and Factors of Loading—B.G.A. Regulations for Airworthiness—R.R.G. Strength Regulations—Comparison of British, German and American Methods and Explanations of Conditions

CHAPTER II. GENERAL LAY-OUT FOR DESIGN, AND WEIGHTS 13

Weights of Main Units—The Choice of an Aerofoil—The Plan Form of the Main Planes—Braced or Cantilever ?—Oscillation of Wings—Position of Struts—Fuselage Shape—Size of Control Surfaces—Centre of Gravity (C.G.) and Wing Position—Angle of Incidence—General Arrangement Views of Sailplane—Performance.

CHAPTER III. MAIN PLANE LOADS AND FORCES . 40

Load Curve—Bending Moment Diagrams for Flying and Landing Conditions—Reactions at Supports and Load Diagrams—Shear Forces—Distributions of Loads in Spars for C.P.F., C.P.B. and L.N.D. Conditions.

CHAPTER IV. DESIGN OF MAIN PLANES 52

Spar Arrangement—Spar Sections—Unsymmetrical Spar Section—Strength of Spars—Main Plane Ribs—Lift Struts—Examples of Main Plane Calculations for Cantilever and Braced Types.

CHAPTER V. DESIGN OF FUSELAGE AND SKIDS . . 71

Types of [illegible] Loads—Design of Fuselage Members with [illegible] Landing Skid—Tail Skid—Wheel Chassis.

Chapter VI. Design of Tail Unit and Control Surfaces 81

Types of Tail Units—Tail Loadings, with Worked Examples—Tail Plane and Elevator Spars—Ribs—Drag Bracing—Rudder—Ailerons.

Chapter VII. Control System and Main Fittings 87

Control System Loads—King-Posts—Cables—Control Column, etc.—Fittings—Worked Examples of Fitting Design.

Chapter VIII. Unusual Designs and Auxiliary Devices 95

Tailless Sailplanes—Ornithopters—Air Brakes—Slotted Wings—Multi-Slots.

Chapter IX. Sailplane Types 113

Wien — Schloss Mainberg — Kakadu — Luftikus — Rhönadler—Fafnir—Austria—Albatross—R.F.D. Sailplane—B.A.C. 7—Phantom—Tern—Scud—Table of Particulars.

PART II

SAILPLANE CONSTRUCTION

Chapter X. The Main Plane 127

The Main Spar—Ribs—The Leading Edge and Trailing Edge—The Wing-Tip—Ailerons—Lift-Struts.

Chapter XI. Fuselage and Empennage . . . 136

General—Monocoque—Braced-Strut, or Girder Type—Skids, Main and Tail—Tail Unit.

Chapter XII. Fittings and Control System . 145

Fittings, General—Leading Edge/Fuselage Attachment Fitting—Main Plane Junction Fitting, "Professor" and "Darmstadt" Types—Attachment Bolts and Pins—Strut-End Fittings—Strut/Spar Fittings—Strut/Fuselage Fittings—Skid Attachment and Launching Hook Fittings—Tail Unit Fittings—King-Posts—Control Cable Connection—Control System, General—Control Column—Rudder Control.

Chapter XIII. Materials of Construction . . 163

Spruce — Ash — Plywood — Steel — Aluminium — Duralumin—Cement—Glue—Fabrics—Brads—Dope—Spliced Joints in Timber—Launching Elastic—Wires—Cables, etc.

PART III

SAILPLANE PILOTAGE

PAGE

CHAPTER XIV. THE SOARING SITE 168
Winds, Direction and Velocity—Wind Roses—Dimensions of Site—Site for Distance Flights—Launching and Landing.

CHAPTER XV. PILOTING A SAILPLANE 178
Launching—Mechanical Launching—Turning—Soaring—Speed of Flight—Landing.

CHAPTER XVI. METHODS OF SOARING AND SAILING FLIGHT 191
Hill, or Contour, Soaring—Convection Soaring—Cloud Flying—Storm Soaring—Gust Soaring or Dynamic Flight.

CHAPTER XVII. AERO-TOWING AND AUTO-TOWING . 207
Towing Aeroplane and Apparatus—The Cable—The Towed Sailplane—Taking Off and Climbing—Aerodynamic Forces set up in Towed Flight—Worked Examples—Effect of Speed—Auto-Towing.

CHAPTER XVIII. FLYING INSTRUMENTS . . 218
Air Speed Indicators—The Altimeter—The Variometer—The Compass—The Baragraph.

APPENDICES

I. THEORY OF INDUCED DRAG 225

IA. METHOD OF OBTAINING POLAR OF AEROFOIL FOR ASPECT RATIOS OTHER THAN THAT FOR WHICH TEST RESULTS ARE AVAILABLE 229

II. AEROFOIL CHARACTERISTICS 232

III. B.G.A. REGULATIONS GOVERNING MECHANICAL LAUNCHING 246

IV. B.G.A. REGULATIONS GOVERNING AUTO-TOWING 248

V. B.G.A. REGULATIONS GOVERNING AERO-TOWING 252

VI. B.G.A. INSPECTOR'S REPORT ON CONSTRUCTION OF GLIDER FOR CERTIFICATE OF AIRWORTHINESS 254

VII. STRENGTH AND OTHER TABLES, CURVES, ETC. . 257
Strength and Weight of Birch Plywood—Extra Flexible Steel Wire Rope for Auto- and Aero-Towing—Sizes and Strengths of Streamline and Swaged Wires—High Tensile Steel Wires—Weight and Strength of Materials—Conversion of English to Metric Weights, Measures and Velocities—Curves for Spruce Struts, Limiting Stress (Robertson), Grades A and B Spruce—Curves for Tubular Steel Struts, Limiting Stress for 28-ton Steel.

INDEX 265

LIST OF SYMBOLS USED

A = Area, of a surface or cross section.
S = Span, of a plane.
s = Semi-span, of a main plane.
C = Chord, of a plane.
Λ = Aspect ratio of a plane $= S^2/A$.
A = Area under a curve.
$\bar{x}$ = Horizontal distance of the centroid of an area from a reference point or line.
$\bar{y}$ = Vertical distance of the centroid of an area from a reference point or line.
I = Moment of inertia of a cross section.
E = Modulus of elasticity.
W = Weight.
w = Unit weight, or distributed load per unit length.
P = Air load.
L = Lift component of an air force.
D = Drag component of an air force.
R = Resultant force (generally an air force).
K_L = Coefficient of lift.
K_D = Coefficient of drag.
K_R = Coefficient of total air force.
K_m = Moment coefficient.
ρ = Air density = 0.00237 slugs per cu. ft. (sometimes taken here as 0.0024).
α = Angle of incidence of a plane to the air flow.
C.G. = Centre of gravity.
C.P. = Centre of pressure.
C.P.F. = Centre of pressure in the forward position.
C.P.B. = Centre of pressure in the back position.
L.N.D. = Limiting nose dive.
V = Velocity.
V_S = Sinking velocity.
B.M., M. or μ = Bending moment.
S.F. = Shear force.

p = Bending stress.
f = Shear stress.
f_s = Horizontal shear stress.
f_t = Torsional shear stress.

Where other symbols have been used, their definitions are stated.

B.G.A. = British Gliding Association.
R.R.G. = Rhön-Rossitten Gesellschaft (the body governing gliding in Germany).
R.Ae.S. = Royal Aeronautical Society.
A.M. = Air Ministry (British).

INTRODUCTORY

The Evolution of the Sailplane

GLIDING provided the means of producing powered flight. All the earliest attempts at heavier-than-air flight were made with motorless craft, beginning with the crude bat-wing type, with which stability was retained by movements of the pilot's body, and of which those built by Lilienthal were typical. Directional and stabilising planes were added by Pilcher, and finally the Wright Brothers made the control surfaces movable and incorporated warping wings as ailerons. Their machine was therefore controlled on precisely the same principles as exist in the present-day aeroplane, so that it is not surprising that the addition of an engine enabled the first power driven, heavier-than-air, flight to be realised.

At this stage the glider was forsaken, whilst the aeroplane was developed, and very little was done with motorless flight until the year 1919, although there were still a few far-seeing enthusiasts who believed in the future of such flight.

The limitations imposed on Germany by the Treaty of Versailles acted as an impetus for motorless aviation, and in this direction their energies were applied. Commencing with ordinary gliders, and by improving performances with better aerodynamic design, soaring machines capable of flights of considerable duration were soon produced.

Encouraged by success, design was still further improved, with a view to accomplishing distance sailing flights and thus the sailplane was gradually developed.

By this time performances continued to improve, duration flights increased and sailing flights extending to first five miles, then twelve miles, and again to thirty miles were carried out. Hill soaring, in the up-currents caused by the wind's deflection, was followed by cloud soaring and storm sailing and again by convection soaring, and so the sailplane has slowly taken its place among the types of successful aircraft.

Gliding was then taken up by other countries, and in England the British Gliding Association was formed towards the end of 1929, which marked the real introduction of motorless flight in this country. Since then many clubs have been formed and sailplaning is rapidly becoming a popular form of aviation.

The Value of Gliding, as a Sport and for Research

As a sport, gliding is unparalleled. It entails a certain amount of hard exercise and, since it is carried out in the open air, it is clean and healthy. Hills are required for soaring flight, and this generally ensures the use of some of our wildest and most picturesque country. The absolute silence, undisturbed by the roar of an engine, and free from the smell of petrol and oil, makes an appeal not experienced in powered flight.

Also it is an all-the-year sport. An average soaring site allows sailing flight to be carried out on at least half the days of a year, and the number of occasions on which operations have to be entirely suspended are remarkably few.

Gliding is the finest and most natural method of teaching flying. The pupil gains confidence and self-reliance from the beginning, as he is the sole occupant of the machine on all flights. A start is made with ground slides, followed by short flights, gradually extended in height and length, until he is capable of soaring. There are no pronounced gaps, comparable with the first solo flight in an aeroplane. Furthermore he is taught to use his own judgment and skill instead of relying on instruments, thus developing the senses of touch, feel (air pressure on face, etc.), sight and hearing. No instruments are used until an advanced stage is reached.

Sailplanes represent the highest degree of efficiency attained in aeronautical design and are in some respects more advanced than the best aeroplanes, so that to-day aeroplane design is based, to some extent, on sailplane experience.

Apart from this, gliding provides an effective proving ground for new designs and types, and may be used as a stepping-stone between the wind tunnel and full-scale flight.

In Germany models are first fashioned and flown. These models have spans of about 8 ft. and are launched in a similar manner to gliders. A machine large enough to carry a pilot

is then built and, after some gentle gliding flights, if no defects are apparent, it is flown as a sailplane. Necessary modifications are incorporated at each stage and, if all goes well, a full-scale aeroplane of the same type is constructed. From this it is seen that not only are the risks of failure reduced to the absolute minimum, but the finished product derives the benefits from the various stages through which the design has progressed.

The Safety of Gliding

The chief dangers with ordinary flying are the results of stalling near the ground and the tendency to catch fire after a crash. Fire is, of course, out of the question with gliders, while the effects of stalling are seldom serious. The sailplane pilot learns to keep his craft at the most efficient altitude during the whole flight, or he must lose height and perhaps terminate his flight. The machine is very often close to the stalling point, but this develops familiarity with the phenomenon of stalling so that its approach is quickly sensed and the stall avoided.

Nevertheless, stalling conditions are sometimes reached, and if the glider is near the ground, a crash is almost inevitable, but even so the pilot generally escapes unhurt. Sailplanes, when stalled, tend to spin, but flying speed and control can be regained after a descent of some few feet. As a rule the wings remain nearly horizontal, forming, what is termed, a flat spin, and several cases have been known of such spins to earth with no damage having been done to the pilot.

The Future

The future for motorless flight is full of promise. In the earliest days soaring could be carried out only in a strong wind from a hill-top. Better machines made possible light-wind soaring, and sailing flight along the hillside. Then cloud sailing was introduced, which extended the range of flight and enabled excursions to be made in directions other than along the range of hills. Convection soaring is the most recent development, and is as yet in its infancy. Flights may be made by this means in any direction independent both of the configuration of the land and of the wind direction and

strength. Long flights have already been accomplished by this method, and these have shown how little we really do know of the air currents.

There is much to be learnt concerning the formation of the masses of vertically moving air and where they may be found. If these air streams retain their positions more or less constantly, then the current systems will have to be plotted and, again, the air flow at different altitudes is likely to vary to some extent, so that a pilot may be able to fly on an almost straight course from one place to another by suitably adjusting his height.

The next few years are likely to bring out the full importance of this source of energy, and it is not without the realms of possibility that one day will see the commercial exploitation of this form of transport.

Up to the present aeroplane towing has been used for giving the sailplane the necessary initial height, but before long some other method of gaining height may be introduced, for use with both convection and cloud sailing, so that flights may be started from flat country. One solution is offered by auto-towing, or towing the sailplane behind a motor-car, whilst the possibility of fitting some kind of rocket apparatus has received some attention. An advantage of the last method is that spare charges could be carried for use "en route" or in the case of an emergency landing.

Lastly, there is no reason to suppose that designs have yet reached finality. In a very short time it should be possible to travel by sailplane in any direction, under almost all weather conditions, and over hilly or flat country alike.

PART I

SAILPLANE DESIGN

B

CHAPTER I

Strength Requirements

Strength Requirements and Factors of Loading—B.G.A. Regulations for Airworthiness—R.R.G. Strength Regulations—Comparison of British, German and American Methods and Explanations of Conditions.

Strength Requirements and Factors of Loading

Sailplanes are motorless aeroplanes having similar main structures and control systems to those of power-driven air craft. The manner of flight is the same, but, owing to the absence of engine power, the manœuvring qualities of sailplanes are considerably restricted.

All aircraft are built to withstand (with a factor of safety—generally two) the loads which it may be reasonably expected that they shall be called upon to endure; not the maximum load it is possible to subject them to.

In other words, pilots are permitted to manœuvre their machines in such a way that all requirements, normal to the type of craft being flown, can be executed without unduly stressing any portion of the structure.

The worst cases of loading to which sailplanes are subjected occur under the following conditions:

1. Level flight in high gusty wind,
2. Pulling sharply out of a steep dive,
3. Launching,
4. Cloud flying, and
5. Spinning.

Of these conditions, case 2, pulling out of a steep dive, could impose such stresses that few, if any, sailplanes would come safely through the test. This applies equally to power aeroplanes, but, however, such mishandling is never done. The forces present during launching resemble fairly closely the forces in pulling out from a dive, but are seldom as severe.

Most sailplanes are fitted with "pendulum" type elevators, i.e. without a fixed tailplane, and this has the effect of making

them very sensitive and uncomfortable at high speeds which in itself is a measure of safety.

Loading, of twice normal, is likely to be experienced in a high gusty wind and up to three times normal in cloud flying, owing to the rapid vertical oscillation caused by the unstable air conditions.

Spinning is not done voluntarily, but sometimes occurs as the result of a stall, or through the pilot losing his balance during flying in clouds.

The worst case is likely to be that of cloud flying, and if the sailplane is designed for this condition it will be strong enough to withstand loadings due to cases (1) and (5), and will also allow for the pulling out of a reasonably fast dive and for a vigorous launch.

Machines used for auto-towing are not liable to greater stresses than in the cases considered, except for local loads at the attachment point, unless done at high speed, but sailplanes used for towing by aeroplane should be specially designed for the higher speed of the towing craft.

B.G.A. Regulations for Airworthiness

The following load factors have been laid down by the British Gliding Association for employment in all glider design:

Main Planes.	Case	(*a*)	Centre of pressure forward. Factor 6.
	,,	(*b*)	Centre of pressure back. Factor 4.
	,,	(*c*)	Nose dive. Factor 1.
	,,	(*d*)	Inverted Flight. Factor 3.
Tail Planes.	,,	(*a*)	To be designed to withstand the loading imposed in pulling out of a dive so that the tailplane will collapse simultaneously with the main planes.
	,,	(*b*)	Nose dive. Factor 1.
Rudder.			To withstand maximum loading with Factor 2.
Fuselage.	Cases	(*a*)	and (*b*) as cases (*a*) and (*b*) for tail-planes.
	Case	(*c*)	Launching. Factor 4.
Landing Gear.	Factor 4.		

Proof of static stability is also necessary and satisfactory flight tests must be carried out.

The Air Ministry Handbook of Strength Calculations, A.P. 970, is to be followed as far as applicable.

Rhön Rossitten Gesellschaft Strength Regulations [1]

Wing Group.	Case 1.	Stress corresponding to flight with most forward position of centre of pressure. Factor 6.
	„ 2.	Stress corresponding to flight with maximum torsional load. Factor 1.
	„ 3.	Stress corresponding to a landing (wing weight as load). Factor 6–8.
Fuselage Group.	„ 1.	Stress due to load on empennage. Breaking load of empennage is breaking load of fuselage.
	„ 2.	Stress by landing. Breaking load of fuselage to be 6–8 times wing weight.
	„ 3.	Stressing of wing fuselage connection by landing on wing-tip. Breaking load of 110 lbs. applied at wing-tip in direction of wing chord.
Enpennage Group.	Elevators and rudders. Breaking load 31 lbs./sq. ft.	
Aileron Group.	Ailerons. Breaking load of 16 lbs./sq. ft.	

The polar diagrams of the wing and of the complete aircraft to be used in the strength calculations.

Proof of static stability also required.

Comparison of Methods and Explanation of Conditions

Main Planes.—Dealing first with the main planes, the first cases of both methods are identical and refer to the sudden pulling up of the sailplane to the attitude of maximum lift

[1] The Development, Design and Construction of Gliders and Sailplanes, Lippisch, Lecture before R.Ae.S., January 29, 1931, R.Ae.S. Journal, July, 1931.

when flying at high speed. The wings are subjected to bending and to forward thrust.

The second case in the B.G.A. requirements is equivalent to that of absolute maximum horizontal speed of an aeroplane with engine speed full out. With sailplanes the condition is taken as the highest speed the aircraft is likely to attain without diving steeply. The definition is somewhat vague, but the case may be taken as representing a speed of twice times stalling speed. In America the equivalent requirement specifies the speed at an angle of glide of 1 in 6.

With symmetrical aerofoil sections and sections with stationary centres of pressure, the C.P.B. position is reckoned as being one-tenth chord back from the C.P.F. or normal C.P. position.

Case (*c*), the nose dive case, deals with loads imposed during the terminal velocity in an almost vertical nose dive, that is to say when the aircraft is diving at its optimum angle for high speed and has reached the limiting velocity. The weight of the machine is assumed to be equal to the total air resistance.

The method of calculating the tail load for this condition is given in A.P. 970, but a formula sufficiently approximate for sailplane design is given here.

Referring to Fig. 1, the maximum tail load,[1]

$$P = \frac{W}{K_R} \quad \frac{\sqrt{(p + e\ K_R)^2 + (a+q)^2\ K_R^2}}{l + a + q}$$

Where $K_R = K_D + K_B$,

p = No lift moment coefficient of aerofoil,

q = Slope of $K_M - K_L$ curve $= -0.25$ for most monoplane aerofoils.

ec = Arm of resultant drag (including wing drag) about C.G.

c = Average chord of main plane.

Having determined the figure for the tail load, the forces on the main plane can be found.

Actually the terminal velocity is seldom reached with power aeroplanes and in fact a height of several thousand feet is required for obtaining such speed. With sailplanes it can safely be said that terminal velocity is never reached. The

[1] See Air Ministry publication, A.D.4., Memo. 65.

highest speed ever attained in diving has most probably been gained as a result of a loss of balance in cloud flying.

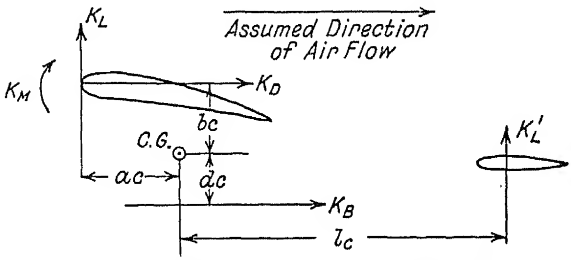


FIG. 1.—Maximum Tail Load in Nose Dive.

In both cases (*b*) and (*c*) torsion loads are caused in the main planes.

The German method includes, instead of the last two cases, case 2, which covers flight with the maximum torsional load.

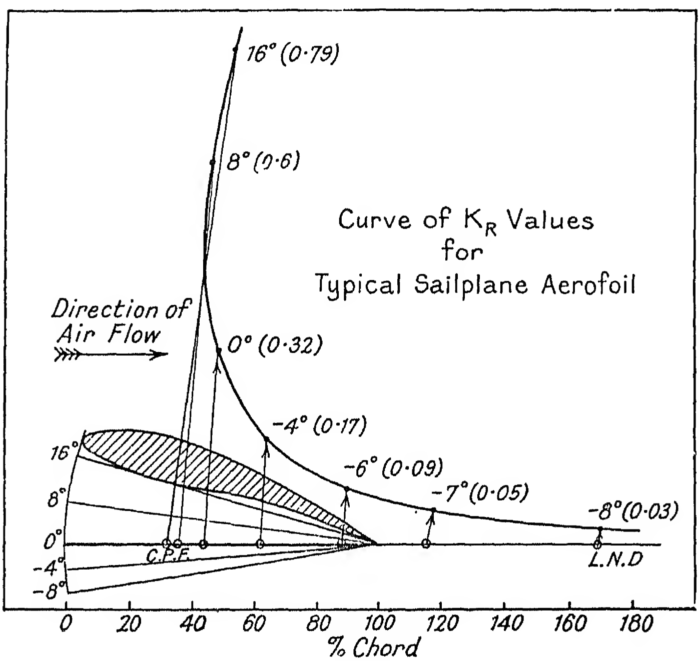


FIG. 1A.

This occurs during a dive at high speed when the angle of incidence is at, or close to, the zero lift position.

The polar for the wing section, for the aspect ratio adopted, is set out by plotting K_L against K_D, and on the same diagram the moment coefficient, K_m, is plotted with K_L as ordinates. (See Fig. 2.)

The intersection of the two curves determines the conditions for maximum torsion, and the values of K_m and K_D can be read off.

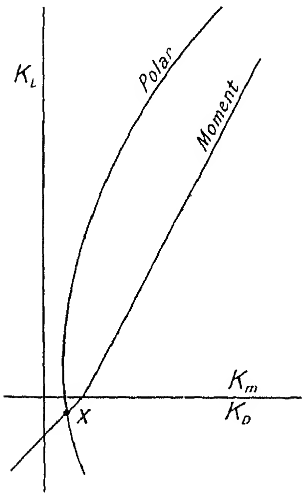


FIG. 2.—Conditions for Maximum Torsion.

The torsion moment is obtained from the formula:

$$M = K_m . \rho . A . V^2.$$

The velocity at which this occurs, may be found by assuming the total resistance as equal to the weight, whence

$$V^2 = \frac{W}{\rho . A . K_R}.$$

The coefficient of total resistance, $K_R = K_D + K_B$, as before, and, unless the drag of the fuselage and tail, K_B, is known, from wind tunnel tests, a value between 0.005 and 0.01, according to the aerodynamical shape, may be used.

There is no inverted flight case under the R.R.G. Regulations, but there is instead, the case of landing with the wing weight as load, for which a factor of between 6 and 8 is allowed. In America the inverted flight case is used with factor 2.5, the factors for C.P.F. and C.P.B. being 6 and 4.25 respectively.

Tail Plane and Elevator

The tail plane loads obtained by the B.G.A. and R.R.G. methods vary considerably, that obtained by the latter method being, generally, the more severe. The distribution of these loads over the tail plane is more complex in the British method, however, so that the nett effects are comparable.

Fig. 3 shows the pressure distribution over the tail planes, as laid down by the R.R.G. (*a*) is for "pendulum" type elevators where there is no fixed tail planes, and (*b*) is for tail plane and elevator.

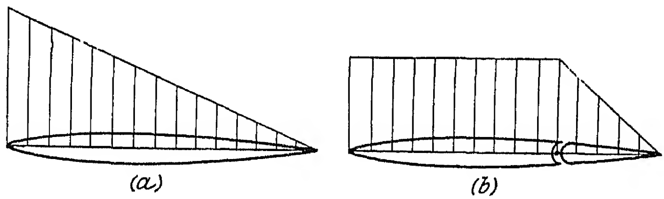


FIG. 3.—Tail Load Distribution, R.R.G.

It will be noticed that with the "pendulum" type it is assumed that there is no torsion effect on the main spar, provided that the axis of rotation is placed at one-third chord from the leading edge, as is usual in such cases.

In the terminal nose dive, used in the British system, it is assumed, from test results, that the tail load acts downwards at the leading edge, giving a load distribution as shown in Fig. 4. This places a heavy down load on the front of the tail and an upward load on the rear, so that the total load

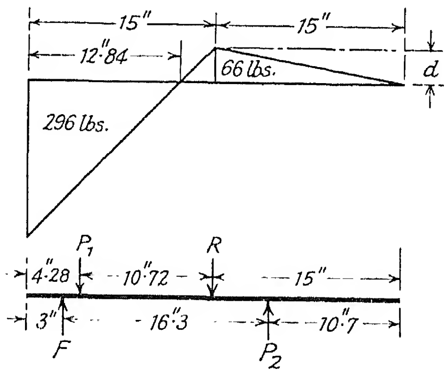


FIG. 4.—Tail-load Distribution in Nose-dive Case.

$$P = P_1 - P_2$$

$$P_1 = P\left\{\frac{(2-E)^2}{(1-E)(2-E)+1}\right\},$$

$$\text{and } a = \frac{(1-E)\ (2-E)}{(1-E)\ (2-E)+1}$$

where the chord = unity, and $E = \dfrac{\text{elevator chord}}{\text{total chord.}}$

This applies to the case of a fixed tail plane with hinged elevators attached. For "pendulum" elevators, of symmetrical section, it should be safe to use a triangular loading distribution, decreasing to zero at the trailing edge.

When the rear spar load for the nose dive condition is only slight, it should be designed for an up-load in normal flight. A suitable value for this may be taken as 5 lbs./sq. ft., with the C.P. at 0.5 chord, and a rectangular loading curve.

There are instances in which the terminal dive load on the tail plane is only slight, in which case some other criterion of strength is necessary.

In this case the highest loads are likely to occur in a sudden pull out from a fast dive, and as the main planes are designed so that they will stand up to a loading of only N times normal, where N is the factor employed, there is no need to make the tail plane, and fuselage, stronger than this.

Suppose the sailplane is pulled out of a dive and immediately changes to the C.P.F. position, such that the main planes are at breaking point, then the speed at which this occurs is

$$V = V_S \sqrt{6} \text{ or } 2.45\ V_S \text{ in ft./sec.}$$

Hence the tail load will be $K_L.\rho.A.V.^2 = .0012\ A(2.45\ V_S)^2$, assuming a value of 0.5 for K_L, and the tail plane should be designed for this.

Rudder

The rudder loading is much more severe in the German method. The British formula is :

Side load in lbs. $= .0012\ A(1.4\ V_S)^2$, multiplied by a factor 2.
where A = area,
and V_S = stalling speed of aircraft in ft./sec.

Since most sailplanes stall at about 40 ft./sec., the average load per sq. ft. $= 7\frac{1}{2}$ lbs. approximately. A triangular loading curve is assumed.

The German figure is 30 lbs./sq. ft., but this may be on account of the interchangeability between elevator and rudder often allowed for.

Fuselage and Landing Gear

The fuselage is subjected to the loads transmitted from the tail planes, subject to a reduction due to inertia effects, but

as this is difficult to determine, it is neglected and the full tail plane loads are therefore used.

In the landing case the wing weight is considered as the load and as acting through the point of contact of the main skid with the ground. Small loads are sometimes transmitted through the tail skid, both in landing and in taking-off, but these are not likely to be great and can be neglected except for consideration of the tail skid itself.

It will be noticed that the R.R.G. regulations include a case to take wing tip landing into account. Landings are

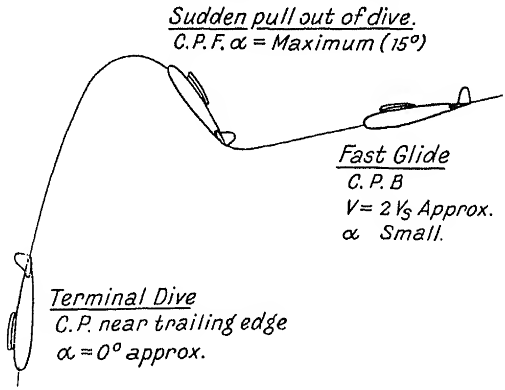


FIG. 5.—Conditions of Loading for Main Planes.

sometimes made so that a wing tip touches the ground, and in some cases the wing tip touches first so that the machine is swung into wind with the wing tip as pivot.

Ailerons

The British method assumes a load under C.P.B. conditions in proportion to the aileron chord relative to the main plane chord. This load is then considered to have a triangular distribution, the load vanishing at the trailing edge and having a C.P. position at one-third chord from the front.

The R.R.G. takes a loading of 16 lbs./sq. ft.

In all control surfaces the torsion induced must be taken account of.

The American requirements for control surface loads are: tail plane and elevators, 12 lbs./sq. ft., with rudder and ailerons, 9 lbs./sq. ft., which agree fairly well with the British figures.

Control System Loads

Suitable loads for the control system may be taken as follows:

Push, or pull, on top of the control column, of 75 lbs.

Side load on top of the control column, of 40 lbs.

Tangential force on rim of the hand wheel, of 40 lbs.

Push on one side of rudder bar, of 150 lbs.

Simultaneous push on each side of rudder bar, of 180 lbs.

A factor of 1.25 should be present in all cases.

These loads are intended for the maximum forces the pilot should reasonably be called upon to exert in an emergency. A sailplane needing such loads for controlling purposes would be considered decidedly heavy on controls and would be most unpleasant to fly.

Fig. 5 indicates approximately the attitudes of a machine under the different conditions considered and shows the movement of the centre of pressure over the main planes.

The British Gliding Association Regulations for Auto-towing and Aero-towing are given in Appendices IV and V.

CHAPTER II

General Lay-out for Design, and Weights

Monoplane or Biplane?—Weights of Main Units—The Choice of an Aerofoil—The Plan Form of the Main Plane—Braced or Cantilever?—Oscillation of Wings—Position of Struts—Fuselage Shape—Size of Control Surfaces—Centre of Gravity (C.G.) and Wing Position—Angle of Incidence—General Arrangement Views of Sailplane—Performance.

It is a little difficult to say which is the first item for consideration in an entirely new design. Generally the designer has a few ideas in his own mind of the main features of the sailplane he intends to produce, or alternatively he is supplied with certain specified requirements and has to build up his design round these.

Most probably a rough estimate of the size and weight, and perhaps the wing section, he intends using are already determined before any paper work is commenced. Most sailplanes built to date have been monoplanes, and consequently this type will receive chief consideration throughout this book.

Monoplane or Biplane?

The question of employing one or two main planes for the design of sailplanes is not so acute as with power aircraft, and in fact very few biplane sailplanes have been constructed.

Structurally the biplane suffers from a great disadvantage owing to the small height of sailplane bodies. On account of this fact, almost all monoplane wings are fitted at the top of the fuselage, or above the fuselage with a connecting neck, which means that if a reasonable gap between the planes of a biplane is to be obtained, the upper wing must be supported, by means of struts, well above the body.

Apart from this the effect of superposing the main planes is to cause detrimental changes in the aerodynamical qualities which are specially marked with wings of large span. The biplane combination suffers from a loss in maximum lift of

about 10% with a similar, or larger, increase in minimum drag, and a reduction in maximum L/D, amounting to as much as 25%.

Some improvement on these figures could be effected by employing a combination having wings of unequal span and area, known as a sesquiplane. The best such arrangement, for a sailplane, would appear to be one in which the smaller plane is on top, in order to keep the attachment struts and fittings as small and light as possible.

Such an arrangement, in comparison with a monoplane, would allow of a lighter structure, a smaller span, and would possibly facilitate folding for transport purposes besides being less liable to stall, but against this must be placed the greater cost of production and repair, and the greater difficulty in, and time required for, erection and dismantling that would probably be entailed.

At the present stage of sailplane development the monoplane seems to offer the most efficient solution.

Weights of Main Units

The weight of each component unit is calculated or based on experience of previous machines, these units being the wings, fuselage, tail, (and pilot).

The earlier sailplanes were built with maximum lightness as the factor of foremost importance. To-day, however, conditions of flight are more severe, machines are put to much greater use, and they are being continually handled, dismantled and erected.

This has led to the employment of higher factors of loading, added to which robustness has become a feature of importance.

Wing weight varies from about 0.9 to 1.2 lbs./sq. ft., and as the area of most sailplane wings is in the neighbourhood of 200 sq. ft., this gives the wing weight as between 180 and 240 lbs., or an average of 210 lbs. Wings built to the smallest figure given have generally experienced fairly high deflections at the wing tips when in flight. A more accurate formula, deduced by Dr. Lachmann, gives the weight as $W = mA + s^3/n$, where s = half span in ft.

$m = 0.78$ lbs./sq. ft., and

$n = 305$ cu. ft./lb. for cantilever, or

$= 560$ cu. ft./lb. for braced monoplane.

Thus if a span of, say, 54 ft. were employed with an area of 200 sq. ft., as before, we get

$$W \text{ cantilever} = 0.78 \times 200 + 27^3/305 = 220.5 \text{ lbs.}$$

and W braced $= 191$ lbs.

These figures agree quite well with those shown above.

From this it is seen that the weight saved by adopting a braced wing is about 30 lbs.

The weight of the fuselage varies approximately in proportion to the length, good average figures being $5\frac{1}{2}$ to 6 lbs. per foot length. The fuselage length in turn varies according to the main plane span and is generally from 35% to 45%, or an average of 40% of the span. Thus for the main planes considered, the fuselage would have a length of about 21.5 ft., weighing 125 lbs. These figures refer to the monocoque type fuselage and could be nearly halved for a fabric-covered body, though the latter type is very seldom used.

Sailplane fuselages have a smaller ratio of length to the span than is general with power machines. Further shortening decreases the moment of inertia, which is beneficial for manœuvring purposes, but tends to cause undue sensitiveness of the elevator controls.

With short fuselages larger tail and rudder surfaces are required, besides which the control surfaces are brought closer into the disturbed air region behind the wing, and they are, moreover, blanked to a greater extent by the fuselage, due to its smaller thickness ratio.

The weight of the complete tail unit should be about 15 or 20 lbs.

An empirical formula for finding the combined weight of fuselage and tail unit, again due to Dr. Lachmann, is

$W = ks$, where $k = 4.4$ lbs./ft. and $s =$ half span, as before.

This gives a weight of $4.4 \times 27 = 120$ lbs., say.

The pilot's weight is usually taken as 150 or 160 lbs. unless the machine is being specially designed for a particular pilot.

The weights roughly adduced are then as follows:

Wings	220	lbs. (cantilever).
Fuselage	115	,,
Tail unit	15	,,
Pilot	150	,,
Total ..	500	,,

This gives, for a main plane area of 200 sq. ft., a wing loading of 2.5 lbs./sq. ft.

An analysis of the most successful sailplanes shows that wing loadings vary between 2.1 and 2.8 lbs./sq. ft.

When a design is completed, or, better still, as each component is worked out, the weights should be calculated by finding the areas and volumes of all main members, and checked up with the original estimates.

The wing section to be employed may now be considered.

THE CHOICE OF AN AEROFOIL

The number of known aerofoil sections that have been tested in wind tunnels, and of which full particulars are available in published form, runs into several hundreds, and the designer is faced with the problem of choosing the apparently most efficient.

This, at first, seems a stupendous task, but if a clear idea is held of the essential characteristics, all but perhaps a dozen quickly become eliminated and a careful selection from the remainder can then be made.

Aerofoil Characteristics

The desirable qualities for sailplane work are:

1. *Good Depth of Section.*—Since all machines of this type, at present in existence, are either pure cantilever, or semi-cantilever, of very considerable span, deep spars are required to withstand the consequent large bending moments, besides which rigidity in torsion also calls for a wing of thick section. These first factors at once cut down the range of suitable sections to within reasonable limits.

2. *High Maximum Coefficient of Lift* (K_L Max.).—This is important as it permits quick take-offs, slow landings and a slow flying speed, and is also necessary for gaining the greatest altitude from gusts. For equal areas the wing with the highest lift coefficient possesses the lowest minimum speed and hence the slowest landing speed. This is perhaps the most important factor.

3. *High Maximum Lift/Drag Ratio* (L/D Max.).—This also is a most valuable feature and gives a very good indication of the efficiency of an aerofoil. Obviously good lifting qualities

are required, but unless the drag is reasonably low, the section will be inefficient, and this ratio is a measure of these combined qualities.

4. *High "Power Factor"* $\left(K_L^{3/2}/K_D\right)$.—This ratio is important with power machines since the amount of power required to pull an aeroplane through the air is equal to the product of resistance and velocity. Resistance of a machine, of fixed weight and wing area, is inversely proportional to L/D and proportional to V^2, whilst velocity varies (inversely) as the square root of K_L, so that power varies inversely as $K_L^{3/2}/K_D$. In other words a high figure for this ratio permits small engine power to be used.

In the case of the sailplane, gliding on a downward path in still air, the component of weight due to gravity which acts in the direction of flight supplies the necessary power for forward motion and the smaller this can be made the finer is the gliding angle. It naturally follows that in a rising current of air a high "power factor" will enable a good climbing angle to be maintained.

5. *Small Centre of Pressure Movement.*—It is important that the wing section employed should have a small movement of the centre of pressure between the positions of maximum and minimum angles of attack, since a small total movement enables a lighter structure to be employed owing to the loading on each structural member remaining nearly constant. In other words, if the C.P. remains stationary, the full strength of all components is utilised continuously, thereby reducing the amount of material to a minimum.

6. *Low Profile Drag*.—According to the "induced drag" theory the drag of an aerofoil consists of two parts, these being the profile drag (K_{DP}) and the induced drag (K_{DI}). The former depends only on the cross sectional shape of the aerofoil, and can be considered as the basic drag of a section, whereas the latter is dependent only on the aspect ratio of the whole wing. From this it is seen that an aerofoil should be chosen for its low profile drag.

Curves for K_{DP} should be prepared for the various wing sections under consideration and taken into account when weighing up their respective merits. Fig. 6 shows this done

for three aerofoil sections. A section having low values of K_{DP} over a large range of incidence should be chosen, and since high angles of incidence are made use of to a large extent in sailing flight, low drag at such angles is desirable.

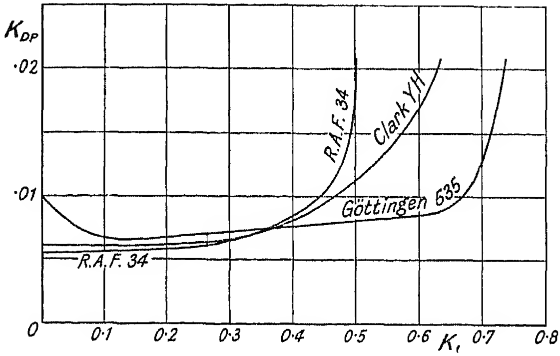


FIG. 6.—Curves for Profile Drag (K_{DP}).

The superiority of Göttingen 535, in this respect, will be noticed.

It is now possible to make a cursory examination of the curves of aerodynamic properties of all available aerofoil sections and to prepare a list of the most promising. These should receive more careful attention and it is as well to draw up the list, together with the chief aerodynamic features, in tabular form. This has been done below, Table I, for a number of suitable sections. (See Appendix II for particulars of wing sections.)

TABLE I

AEROFOIL CHARACTERISTICS

Aerofoil.	Depth % Chord.	K_L max.	L/D max.	$K_L^{3/2}/K_D$ max.	C.P. Movement.
R.A.F. 30	12.64	.575[1]	20[2]	9.8[2]	Stationary.
R.A.F. 34	12.64	.51	20.1	10.3	Almost stationary.
Göttingen 387	15.11	.67	18.6	9.4	Large.
„ 426	13.6	.65	19.5	10.5	Large.
„ 535	16.05	.78	17	9.2	Large.
„ 549	13.85	.665	21	9.8	Large.
Clark Y.H.	11.7	.65	20	10.3	Small.

[1] Corrected for scale effect. [2] Uncorrected.

All figures for this table can be readily estimated from the characteristic curves with the exception of ${K_L}^{3/2}/K_D$, and this must be calculated over a range of angles of incidence.

Fig. 7 shows the " power " factor plotted against lift-coefficient for the sections tabulated, from which it will be noticed that some sections have a sharp peak, whilst others are fairly flat. The flat peaks denote good values of the factor over a large range of angles, a feature of importance.

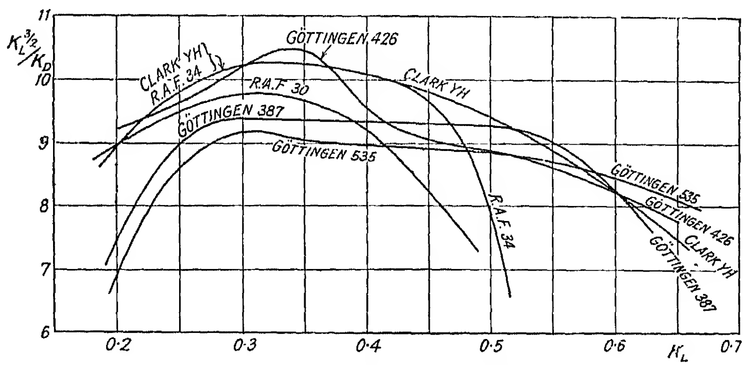


FIG. 7.—" Power Factor " Curves.

Some Eiffel sections appear attractive and may give good results, although, since test results available were obtained under favourable conditions, they may give misleading values.

Göttingen 535 has been used for about 50 per cent. of the successful German machines and is certainly a good general purpose section.

THE PLAN FORM OF THE MAIN PLANE

The shape of the wing in plan is of far greater importance in sailplanes than in any other form of aeroplane. A comparatively inefficient aeroplane can be given a reasonable performance by adding greater engine power, but no such measure can be adopted with sailplanes, which depend solely on aerodynamic efficiency for good soaring flight. Therefore, since the main plane constitutes the chief feature, aerodynamically, of the machine it is essential that it should receive very careful

consideration. A good aerofoil section is not sufficient, alone, to ensure the success of a machine, and in order to obtain the best result the plan form should be so arranged to secure the highest degree of efficiency compatible with a reasonable weight of structure.

Aspect Ratio

The chief variation in form affecting efficient design is the ratio of the span to the chord, or mean chord in the case of tapering wings. This factor, known as aspect ratio, is generally expressed as $\Lambda = S^2/A$, where S is the span and A the main plane area. For rectangular wings the expression becomes S/C, where C represents the chord.

An aspect ratio of about 6 is generally considered sufficient in power machines, but ratios exceeding 20 are not unknown in sailplanes, whilst a good average figure is about 15. Increase in aspect ratio is accompanied by slight increase in lift values, approximately 2% for each unit increase in ratio, and drag also decreases, so that considerable changes in the value of L/D result.

This is particularly noticeable in the maximum L/D ratio, which increases by about 8%, of its value for a ratio of 6, for each unit increase in aspect ratio.

For example, the employment of a ratio of 16 raises the maximum value of L/D by about 80%, or very nearly double the figure for the aspect ratio of 6.

If there were no other factors to consider, it is certain that very large aspect ratios would be used, but the span is restricted by spar depth and weight considerations, besides which, if larger spans are developed than are at present in use,[1] some difficulty would be experienced during landings in confined spaces.[2]

Tapered Wings

Wings tapered in plan have a slight aerodynamic advantage over rectangular wings of equivalent aspect ratio, this being most noticeable at high speeds, but tapered wings also possess

[1] The span of Kronfeld's latest sailplane, the " Austria," is 100 ft.

[2] One important feature of [illegible] ease with which the machines are landed, almost regardless [illegible] in small fields and restricted areas.

a big structural advantage owing to the increasing chord towards the roots being accompanied by increasing thickness, so that the greatest depth of spar occurs where the bending moment is largest.

The weight of well tapered wings is only about 50 to 60% that of rectangular wings of equal span and area. Wings of medium taper would, of course, have a value of between 60 and 100% depending upon the amount of taper.

The parallel chord machine also suffers badly on lateral control, making for heavy control, and increasing the tendency to stall of the inside wing tip during a turn.

The tapered wing, by having the weight concentrated towards the centre, requires less effort to turn, as the inertia forces are smaller.

The ideal plan shape for a wing is elliptical, but the manufacture of planes in the form of an ellipse is rather complicated and in consequence is not very general, although a number of machines have employed very close approximations to this shape.

Since leading edges are, almost without exception, covered with plywood for torsional rigidity, the problem of attaching the ply to the edges of an aerofoil, curved in plan, is by no means easy and for this reason the leading edge is seldom other than straight. The trailing edge, however, lends itself more readily for this purpose and, moreover, an improvement in the aileron qualities can be effected by increasing the aileron chord at its mid-span, so that the trailing edge is often curved to some extent over this portion.

Some slight advantage is gained by curving the wing-tips, and a straight taper with well rounded tips approximates very closely, in aerodynamic efficiency, to the full ellipse and is, of course, much simpler to construct.

The amount of taper for best results should be such that the wing-tip chord is about half that at the centre, although the ratio may be varied between a quarter and two-thirds without appreciable loss of efficiency.

Structural properties are also improved by a large amount of taper, so that a ratio of 4 to 1 is very suitable. Several sailplanes have been built with wing-tips running almost to a point, but wind tunnel tests have shown that this is inferior to a moderate taper.

The effect of aspect ratio on sinking speed has been shown diagrammatically by Herr Lippisch,[1] Fig. 8.

The curve of minimum sinking speed for the various spans has been added.

The approximate sinking speed of a normal type sailplane of 200 sq. ft. area and 55 ft. span is seen to be 2.55 ft./sec.

This is, of course, an aspect ratio of $(55)^2/200$ or 15.

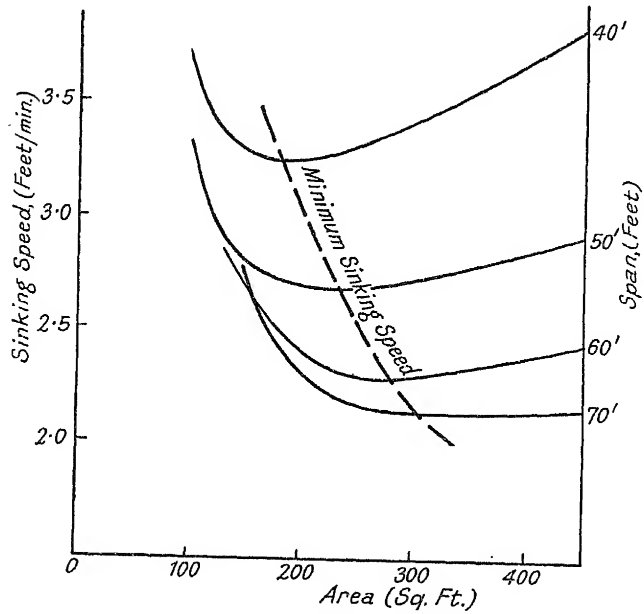


FIG. 8.—Aspect Ratio Effect on Sinking Speed.

The diagram indicates that if the span is kept at 55 ft., the lowest sinking speed attainable is 2.5 ft./sec., with the area increased to 250 sq. ft., or a gain of only 0.05 ft./sec., 2%, for an increase in area of 25%.

Alternatively, if the area remains constant an increase in span to 60 ft. decreases the sinking speed by 0.1 ft./sec. The aspect ratio would now be $60^2/200 = 18$.

[1] Lecture before R.Ae.S., January 29, 1931, by Herr A. Lippisch, R.Ae.S. Journal, July, 1931.

Wash-in and Wash-out

The airflow over the top of an aerofoil tends to flow inwards, i.e. from the tips towards the centre, on account of the negative pressure, and, similarly, the streamlines below the wing tend to converge, due to the increased pressure, as shown in Fig. 9, with the result that the effective chord increases towards the wing tips. The result of this is that the effective angle of attack is reduced, and this can be overcome by slightly twisting the aerofoil so that the angle of incidence is increased at the tips. At the same time it will be seen that a decreased effective angle of attack at the tips will delay stalling over those parts of the wings, thereby improving the efficiency of aileron control at slow speed, so that the value of wash-in is doubtful.

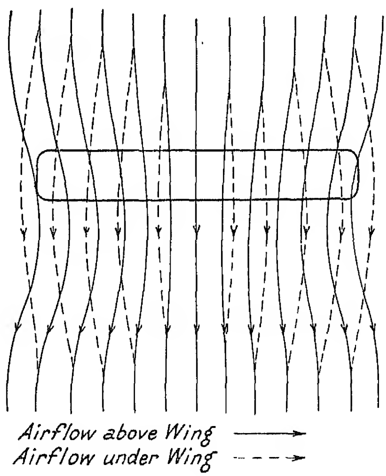


Fig. 9.—Diagram illustrating Airflow over and under Aerofoil.

Wash-out, on the other hand, improves lateral stability, but this is not difficult to obtain in sailplanes and, as wash-out is accompanied by loss of efficiency, its value appears negligible.

Incidentally, the diagram, Fig. 9, explains the formation of the trailing vortices. The air from above and below the aerofoil meets at the trailing edge, but with inward and outward components, which impart a spinning motion to the air.

Braced or Cantilever Wings ?

It has been seen that a saving in weight can be effected by employing braced wings instead of pure cantilever construction. This weight saving is due to the fact that the bending loads and torsional stresses do not reach as high a figure with the former type, which means that shallower wing sections can be used with consequent lessening of drag.

The decreases in both weight and drag would allow of smaller main plane areas with consequent increased efficiency, but, however, these advantages are compensated for by the extra drag of the bracing struts.

On these considerations alone there is little to choose between the two types, though if anything the pure cantilever would appear slightly more advantageous.

A braced wing appears, and, in fact, is, more rigid and thereby gives a bigger feeling of security and confidence to the pilot during flight, apart from which it is better able to withstand the twisting effect of side-wind landings, which have been known to wrench the wing from the fuselage.

Against this must be set the fact that the greater flexibility of the unbraced wing gives better stability in flight, and owing to the ability to ride over gusts, instead of passing through, there is a gain in aerodynamic efficiency. In other words, the wings of a cantilever sailplane oscillate with the gustiness of the wind, and thus extract power from any unevenness in the wind structure.

All things considered, there is little to choose between braced and unbraced, so that it is largely a matter of individual taste.

Oscillation of Wings

The natural frequency of a wing's oscillation can be determined by holding the wing tip and imparting an up and down motion, by exerting a continuous series of small pushes, noting at the same time, by means of a stop watch, the number of wing flexes during one minute.

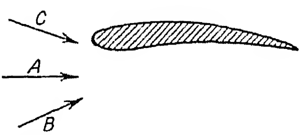


FIG. 10.—Wing Oscillation.

For safety the figure should not be less than 120 complete oscillations per minute, an empirical figure obtained by experiment. In flight such oscillations would be damped to some extent, owing to the air loads on the wings, so that the figure would be somewhere in the neighbourhood of 80 per minute.

The explanation of the danger caused by slow oscillation is as follows :—Suppose a wing is descending, after meeting a gust, the relative air flow will change from the forward direction, A to B, Fig. 10, so that the effective incidence is increased with an accompanying increase in lift, whilst the C.P. moves forward over the wing.

The extra lift obtained causes the wing to rise, which is aggravated at the same time by the C.P. movement, and the pilot tries to counteract this by means of the elevators.

As the wing rises the effective incidence again falls off, the relative air flow now being at C in the Figure, with a loss of lift, whilst the C.P. moves back once more, tending to still further decrease the incidence, and again the pilot tries to correct by raising the elevators.

Now, if the oscillation of the wing is sufficiently slow for the pilot to keep "in step" with the elevator movements, it is easily possible for the pilot to aggravate the wing flexion to such an extent that the wings finally break off.

With an oscillation of high frequency the effect on the attitude and course of the machine is not so pronounced and is, moreover, too quick for the pilot to respond with the elevator controls.

It is difficult to lay down a suitable criterion for the best amount of deflection that should be present in a sailplane wing, but a figure of about 1 ft. in a span of 50 to 60 ft., from the up to the down position, appears fairly reasonable.

It is inevitable that there should be considerable flexing with cantilever wings of large span and the flight of such a machine often appears somewhat alarming to an observer, but it should be remembered that a deflection of 6″ in a semi-span of 30 ft. would be roughly equivalent to one of $\frac{1}{2}$″ with a 15 ft. semi-span, which latter would not cause any alarm.

The frequency of oscillation with most successful sailplanes varies between 150 and 200 per minute.

Position of Struts

The ideal point of support for an untapered wing, or other structure, is two-thirds of the distance out from the root support. Any tapering of the wing causes the loading to decrease towards the tip with a consequent move inwards for the best strut position.

With a normal taper, as generally used in sailplanes, a strut position of about half the semi-span, or even less, would be right.

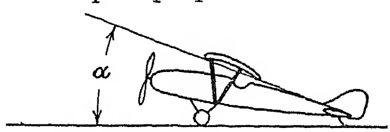
There are, however, other factors which bear upon this point. They are:

(*a*) The weight of struts increases out of proportion to their length.

(*b*) The increase in drag is somewhat greater as the strut length is increased.

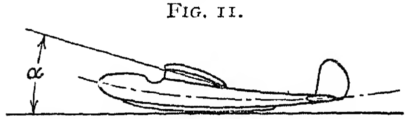
(*c*) The difference in height between the two ends of the strut is fixed by the wing position relative to the ground. This means that as the strut attachment to the main planes is moved outwards the angle between the strut and wing decreases, with a consequent increase in the end load induced in the main spar. Below an angle of about 50° this increase becomes rapid.

(*d*) The main plane is generally divided into three portions for transport purposes. It is undesirable for the strut attachments to be outside the main plane joint, so that a strut position just inside the wing connection fittings is indicated.



Landing Attitude of Power Craft.

FIG. 11.



Sailplane with Up-curved Axis.

FIG. 12.

With a wing divided into approximately equal sections the strut attachment is then fixed as one-third of the semi-span from the root and this has proved to be a suitable position.

Fuselage Shape

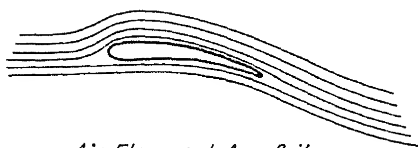
The fuselage should be above all things of good streamline shape, apart from which it has to house the pilot, support the main wing and tail unit, and to have a base that conforms well with the skid arrangement.

The main skid should be kept as close to the body as possible, to keep air resistance to a minimum, and should also allow a good take-off and landing angle for the main plane. The best angle of attack for landing and taking-off is the angle at which the coefficient of lift is a maximum, as this permits the lowest landing speed and the quickest take-off.

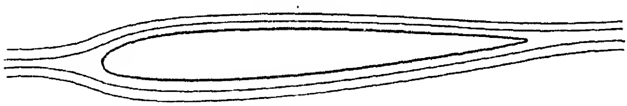
It is very difficult to incorporate all these features in a sailplane and some compromise is necessary. The most efficient angle for attaching the wing to the fuselage is a little coarser than the angle of maximum L/D, for the wing alone, or usually about 3 or 4° incidence. This is obvious since the fuselage increases the total drag, to compensate for which the

wing must be set at a slightly greater angle and so obtain a higher lift coefficient.

This position must be adhered to for highest efficiency in flight, whilst for landing the angle of attack should be in the neighbourhood of maximum K_L, for the section employed (generally about 15°). In the case of power machines this presents little difficulty since the increase in the angle of attack can be obtained by means of the height of the undercarriage. (See Fig. 11.) This height is generally necessary in any case to protect the propeller against damage through contact with the ground.



Air Flow past Aerofoil.



Air Flow past Fuselage

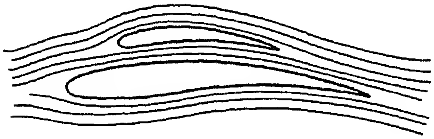
FIG. 13.

The only possible methods of obtaining so large a landing angle on sailplanes, apart from using a completely adjustable wing, are by (*a*) employing a very deep skid. An impracticable method resulting in loss in flying efficiency ; (*b*) increasing the fixed angle of incidence of the wing to the fuselage and thus lose heavily on performance in the air, or (*c*) bowing the fuselage so that the tail is turned upwards. (See Fig. 12.) This is really a special case of (*b*), as the mean fuselage axis has an increased angle with the main plane, besides which the body cannot be made as clean a streamline shape. Apart from all this there is a good reason why the fuselage should curve downwards towards the tail.

Reference to Fig. 13 will show an aerofoil section assumed set at the best position for L/D for the whole machine and below it is a suggested fuselage shape in a horizontal position but dropped clear of the influence of the wing. The streamline

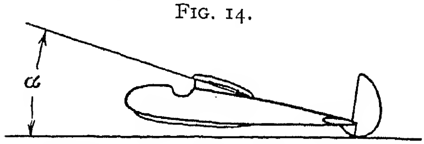
airflow for both is indicated with series of lines, and it will be noticed that, if the two were brought close together, interference would take place, so that to avoid this the fuselage should be shaped to conform with the lines of flow round the wing. Fig. 14 shows the ideal combination.

From what has been said it is clear that either air or "ground" performance must be sacrificed, and, providing a reasonable amount of safety can be provided for, the "ground" efficiency may be lowered to obtain good air performance.



Fuselage Shape to conform with Aerofoil Air Flow.

FIG. 14.



Sailplane Landing at Lowest Speed for Restricted Area.

FIG. 15.

This means that higher speeds with stronger pulls are required for launching and greater landing speeds become necessary. It should, however, be remembered that in an emergency landing in a small space or field the lowest possible landing speed for the wing area used is still available if the nose of the machine is held up, as in a "three point landing," on normal power craft. (See Fig. 15.) The actual contact will be a little heavy, but not dangerous. Also landing speed may be decelerated by running the main skid along the ground, if reasonably flat.

Minimum flying speeds of sailplanes are generally in the region of 25 to 30 miles per hour and normal running-skid landings can be made at up to 35 or 40 miles per hour, which is still quite a low figure. The quick pull-up owing to friction between skid and ground largely overcomes the disadvantage of not being able to utilize the best landing angle for the main plane.

A very important point that should be borne in mind when designing the fuselage is the protection of the pilot in the event of the machine overturning on landing or in a crash. If the pilot's head protrudes above the fuselage and wing, the results of an otherwise minor accident may be very serious, and, unless the wing is situated well above the pilot, it is advisable

to build a very strong fairing that will take the load of the machine in an inverted position.

Cross Section of Fuselage

The cross section of the fuselage should be of just sufficient size to house the pilot with a reasonable amount of comfort, and be so shaped to allow suitable attachment for the main plane above and the skid underneath.

The section most favoured is an oval shape, Fig. 16 (*a*). This shape reduces resistance to the absolute minimum and

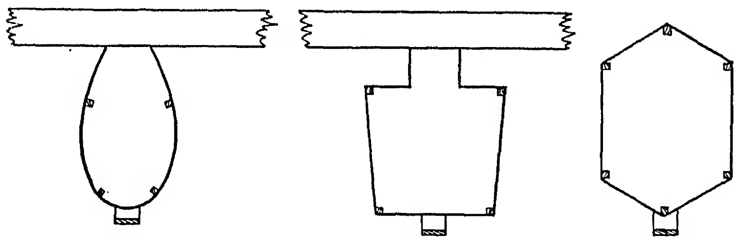


Fig. 16.—Sailplane Fuselage Shapes.

is in consequence the most efficient, but is rather expensive to produce. Cheaper construction is possible with square section, and in this case some reduction of drag is possible by making the base of less width than the top. Fig. 16 (*b*).

A method considerably used is shown at (*c*). This construction employs six longerons placed hexagonally and is fairly easy to produce, provides simple attachment for both skid and main plane, and supplies a fairing for the pilot's head. This section is mainly utilized with strut-braced wings.

It has been found advantageous in practice to place the main plane well above the fuselage so as to keep the wing quite clear of the interrupted flow of air caused by the pilot's head. This is usually allowed for by constructing a " neck " between the fuselage and wing, as shown in Fig. 16 (*b*), the " neck " acting also as a fairing to the pilot's head.

This " neck " is made as an integral part of the body and should be amply strong as the main plane attachment fittings are fixed at this point.

Many sailplanes have the wing attached directly on to

the fuselage so that the pilot's head is just in front of the leading edge, and in some instances the leading edge at this point is cut away to accommodate the head. This not only upsets the air flow over the wing immediately behind, but its influence extends outwards for some distance, thereby reducing considerably the efficiency of the main portion of the wing.

Attempts have been made to cover the whole of the pilot either with a plywood fairing over the top, fitted with apertures, or with a celluloid fairing, but this has not so far met with universal approval owing to the loss of "feel" of the air pressure over the pilot's face.

The feel due to air pressure on the face is very important in gliding flight, both for forward speed and for turning, and only very experienced pilots can fly a sailplane with safety in an enclosed cockpit.

Provision should be made either in the fuselage or on top of the front portion for the housing of instruments, it being usual to carry height and speed indicators, a compass, and a "rise and fall" meter.

Below are appended some notes on the shape of streamline bodies.

CONCLUSIONS OF REPORT ON EXPERIMENTS ON STREAMLINE BODIES.[1]

1. The shape of head is of more importance than the tail.
2. A good head is one which has a small average curvature and emerges very gradually into the parallel portion. A bluff nose is not disadvantageous so long as the curvature of the remainder of the head is well designed.
3. The information about tails is less definite. For a given length of curved portion a pointed tip and greater average curvature in the forward part seem preferable to a blunt tip and a less average curvature.
4. The better the head, the greater the difference due to changes in the tail.

Size of Control Surfaces

The area required for any control surface is dependent on the distance of its centre of pressure from the centre of gravity of the whole machine. It is also affected by the distribution

[1] R. and M., 607.

of weights of the main items forming the total weight, but there is little variation with sailplanes, in this respect, and it can be neglected.

Another factor concerns the speed of flight; the minimum being, of course, the speed to consider, since if there is sufficient control at slow speed there will be ample for higher speeds. Here again there is little variation in sailplane minimum speeds.

It is possible to calculate the rolling moment needed for ailerons or the power required for tail planes to compensate for the main plane centre of pressure movements, but actually the areas are generally based on experience of past successful machines and the following empirical formulæ will be found to give satisfactory results:

$$\text{Area tail (including elevator), } A_{TE} = \frac{0.4\ A\ C}{l} \quad . \quad . \quad (1)$$

$$\text{Area pendulum elevator, } A_E = \frac{0.365\ A\ C}{l} \quad . \quad . \quad . \quad (2)$$

$$\text{Area rudder, } A_R = \frac{0.7\ A}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\text{Aileron area, } A_A = \frac{1.8\ A}{l_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where A = main plane area

C = main plane mean chord $= \frac{A}{\text{span}}$.

l = distance C.P. surface to C.G. machine.

l_1 = distance C.P. surface to centre line of machine.

It will be noticed that the first two formulæ make allowance for the chord of the main plane. This is because the main plane centre of pressure shift is dependent on the chord, and the elevator forces necessary for control purposes must be proportional to this movement.

A very approximate value of l, for the rudder calculations, is two-thirds of the total length of the sailplane, and 1 to 2 ft. less for the elevators, and for l_1 one-third of the total span.

Considering now the sizes of control surfaces for a typical machine of 200 sq. ft. area, 55 ft. chord and 21.5 ft. in length.

$$\text{Rudder area} = \frac{0.7 \times 200}{14} = 10 \text{ sq. ft.}$$

$$\text{Pendulum elevators} = \frac{0.365 \times 200}{13} \times \frac{200}{55} = 20.4 \text{ sq. ft.}$$

or, with fixed tail plane, the total area $=22\frac{1}{2}$ sq. ft., of which about half should be tail plane and half elevator. Experiments have shown that the exact distribution does not materially matter.

$$\text{Aileron area} = \frac{1.8 \times 200}{18} = 20 \text{ sq. ft. or } 10 \text{ sq. ft. each wing.}$$

All values thus obtained must be checked again when the exact lay-out of the sailplane has been determined.

Differential aileron control, by which is meant the employment of some system whereby the down-moving aileron has a smaller travel than the up-moving aileron, is of great importance in sailplanes. The small amount of movement of the down-turned aileron has a beneficial effect on the drag of the outside plane, thereby assisting the turn and preventing the tendency to stall when turning at slow speeds.

Centre of Gravity (C.G.) and Wing Position

The exact location of the position of the centre of gravity, for the complete machine, is necessary in order to fix the position of the wings, and for this a schematic side elevation is drawn, with the position of all main loads added. Fig. 17.

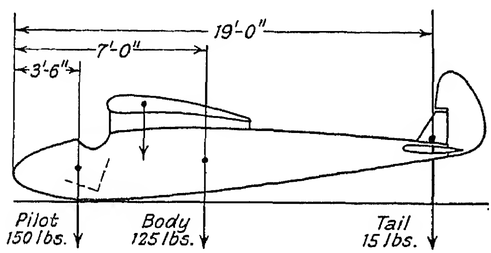


FIG. 17.—Position of Centre of Gravity of Sailplane.

The pilot in a sitting posture will need about 3′ 0″ to about 3′ 6″ from his back to the rudder bar, and should be placed as far forward as possible. The movement of rudder bar, or pedals, must not be overlooked. The centre of gravity of a man in this position is about 1 ft. above the seat and 1 ft. forward of the back.

The fuselage C.G., for want of more exact determination, may be taken as at one-third of its length from the nose, and the tail C.G. position will be near the main tail spar, but just behind and above to allow for the rudder weight.

The C.G. of the wings will depend on the type of construction. If a single spar, with torsion tube, is used, the C.G. will be close to the spar centre, but if two main spars are employed, the C.G. will be somewhere between the two, say at one-quarter or one-third the distance back from the front spar.

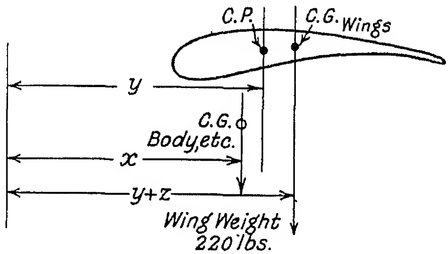


FIG. 18.—Balancing C.G. and C.P.

The weight of the wings consists of front spar, torsion tube, rear spar or false spar, aileron spar and covering. The ribs constitute a small fraction of the whole.

It will be as well now to find the C.G. of the whole, less the wings. For the dimensions and weights shown this will be, by moments about the nose,

$$\begin{aligned} 290 \times x &= 150 \times 3.5 + 125 \times 7 + 15 \times 19 \\ &= 525 + 875 + 285 \\ &= 1685 \end{aligned}$$

$$\text{and } x = {}^{1685}/_{290} = 5.8 \text{ ft. from the nose.}$$

The wing has now to be placed in position so that the centre of pressure will be vertically above the centre of gravity when in normal gliding flight. For most aerofoils this is approximately at one-third chord from the leading edge.

If the C.G. of the wings falls behind the C.P. position, say by a distance z ft., then the wings must be placed over the fuselage with the C.P. behind the C.G. of the machine, excluding wings, so that

$$\text{W (total)} \times y = \text{W (excluding wings)} \times x + \text{W (wings)} \times (y + z)$$

(See Fig. 18).

Thus, if the C.G. of wings is assumed as 3″ behind the C.P. and the C.P. is assumed at one-third chord, say 1′ 6″,

D

$$510\,y = 1685 + 220\,(y + .25)$$
$$= 1685 + 220\,y + 55$$
$$290\,y = 1740$$

and y, the distance from the nose to the C.P. and C.G. (total), $= \frac{1740}{290} = 6$ ft.

The leading edge will then be 6 ft. less one-third chord, or 6′ 0″ − 1′ 6″ = 4′ 6″ from nose, and this agrees well with the position of the pilot's back, which was already fixed provisionally at 4′ 6″.

If the C.G. of wings is in front of the C.P., then the above process is slightly modified.

When the height of the fuselage has been fixed and the vertical position of the wings relative to the body has been determined, the vertical position of the C.G. should be found in a similar manner. In this case the diagram of Fig. 17 is turned up through a right angle, and the skid base is used as datum line from which all measurements are made.

The C.G. position is thus fixed in both directions, and this will be required later when considering the tail load in a terminal nose dive.

Angle of Incidence

The main plane should be set to the fuselage so that the value of lift/drag for the complete machine is a maximum.

If the wing alone were being considered the position of $^L/_D$ max. could be obtained by drawing a tangent through the origin, O, in Fig. 19, to the polar for the aerofoil section used, the polar being obtained by setting out values of lift against drag.

The test results available are generally for aspect ratios of 5 or 6, and if some other ratio value is used, a new polar must be set out for that ratio. The method of doing this is shown in Appendix I, and the new polar for an aspect ratio of 15 is also shown in Fig. 19.

There is also the drag of fuselage and tail unit to be considered. This remains fairly constant throughout the range of angles made use of in flight, and each unit of wing area has, therefore, a small part of the fuselage drag added, to obtain the total drag coefficient.

Drag of fuselage $= A_F \times K_{DF}$

Hence increase to wing drag coefficient $= \dfrac{A_F \times K_{DF}}{A}$

The drag coefficient of the fuselage may be obtained by wind tunnel tests, but failing this an average value may be assumed, provided the fuselage shape does not vary much from those of normal machines.

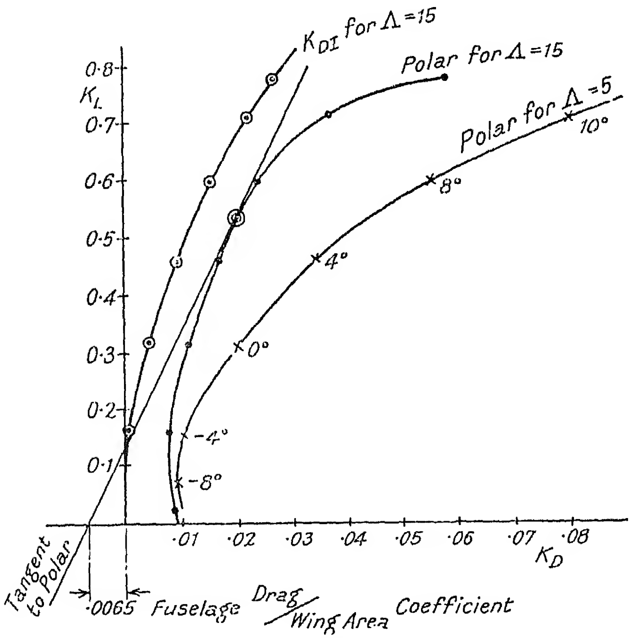


FIG. 19.—Aerofoil Göttingen 535—Polars for Aspect Ratios 5 and 15, and Induced Drag Curve for Aspect Ratio 15.

Values of $\dfrac{A_F \times K_{DF}}{A}$ for past successful machines have varied between 0.005 and 0.01, the average value being 0.0065, which figure may be used for want of more accurate details.

This increment of drag should be added to all values of the wing drag coefficient, but the object can be more simply achieved by moving the origin to the left through a distance

representing the fuselage drag value. This has been done in Fig. 19.

A tangent is now drawn from the new origin to touch the polar, for the aspect ratio being considered, and the lift coefficient at the point noted. For an aspect ratio of 15 the lift coefficient is seen to be 0.53.

The angle of incidence for the aspect ratio concerned, giving the lift coefficient thus obtained, has now to be found.

The employment of a higher aspect ratio has the effect of decreasing the drag. By the Induced Drag Theory the drag of a wing is made up of profile drag and induced drag. The former remains constant for all aspect ratios and it is consequently the induced drag that matters. (This is fully explained in Appendix I.)

The change in the angle of incidence, for the altered aspect ratio, is obtained from the formula given in the Appendix:

$$\alpha_1 - \alpha_2 = 36.5\ K_L\left(\frac{1}{\Lambda_1} - \frac{1}{\Lambda_2}\right)$$

Substituting the present values — $\Lambda_1 = 5$ and $\Lambda_2 = 15$:

$$\alpha_1 - \alpha_2 = 36.5 \times 0.53\left(\frac{1}{5} - \frac{1}{15}\right)$$
$$= 2.58^\circ.$$

For the values considered above, a lift coefficient of 0.53 is seen to represent an angle of attack of 6° for an aspect ratio of 5, which gives the angle required for the higher aspect ratio as $6^\circ - 2.58^\circ = 3.42^\circ$.

Hence the angle of incidence is fixed as 3° 25′.

General Arrangement Views of Sailplane

The following particulars having been provisionally decided, it is now possible to draw out the general arrangement of the sailplane projected.

Area of main plane, span, length of fuselage, size of tail units, size of ailerons and angle of incidence of main plane are all shown on the drawing, Fig. 20.

The height of the tail plane off the ground is obtained from the front elevation by joining one wing-tip to the main skid with a straight line and placing the tail plane in such a position that there will be a clearance of a few inches with the sailplane

resting on one wing-tip. Unless the tail can be placed well above the fuselage it will be necessary to employ a fairly deep tail skid for this purpose, as it is very important that the elevators should not come in contact with the ground.

It is unnecessary to set the main planes at any dihedral angle, for lateral stability, unless the wing is placed below the fuselage, which is seldom done with sailplanes of high span, owing to the danger of fouling obstacles on the ground. When

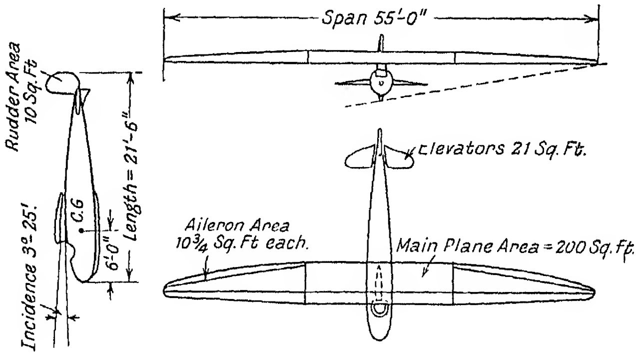


FIG. 20.—General Arrangement Views of Sailplane.

the body is placed below the wing lateral stability is inherent owing to the pendulum effect.

Performance

Stalling or Landing Speed.—The lowest speed at which flight is possible is obtained when the lift coefficient is the maximum for the aerofoil used. It is obtained from the formula :

$$V^2 = \frac{W}{K_L . \rho . A}$$

Thus, if W = 500 lbs., K_L max. = .775 and A = 200 sq. ft.,

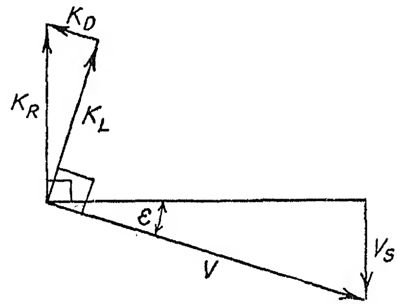
$$V^2 = \frac{500}{.775 \times .0024 \times 200} = 1{,}287,$$

and V = 35.85 ft./sec., or 24.5 miles/hour.

Minimum Sinking Speed.—Sinking Speed, $V_S = V \sin \epsilon$

$$= V.K_D/K_R, \text{ or since } K_R \triangleq K_L,$$

$$V_S \triangleq V.\frac{K_D}{K_L} \quad . \quad . \quad (1)$$



Now $W = K_L.\rho.A.V^2$,

$$\therefore V = \sqrt{\frac{W}{K_L.\rho.A}}$$

and $V_S \triangleq V.\dfrac{K_D}{K_L}$

$$\triangleq \sqrt{\frac{W}{K_L.\rho.A}} \times \frac{K_D}{K_L} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

At normal air density $\rho = .0024$ slugs/cu. ft., and substituting $\dfrac{S^2}{\Lambda}$ for A, where S = span,

$$V_S = 20.4\sqrt{\frac{W\Lambda}{S^2}} \cdot \frac{K_D}{K_L^{3/2}} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From this it is seen that V_S will be a minimum when $K_D/K_L{}^{1.5}$ is a minimum, and values of this may be calculated from the characteristic curve for the aerofoil used, at the aspect ratio employed. It should be noted that K_D will include the fuselage/wing drag coefficient referred to on page 34. Actually the fuselage drag does not remain constant, but for the small angles under consideration it may be assumed so.

A curve for $\dfrac{K_D}{K_L^{1.5}}$ may be plotted against K_L after calculations have been made for several values of the lift coefficient. This has been done in Fig. 21 for Göttingen 535, and is based on the curve of Fig. 19.

The minimum value is seen to be at $K_L = 0.625$ and is then $.0325/(.625)^{1.5} = .0657$.

Using the values of W = 500 lbs. and S = 55 ft., we get

$$V_S = 20.4\sqrt{\frac{500 \times 15}{55 \times 55}} \times .0657, \text{ from (3)}$$

$$= 2.11 \text{ ft./sec.}$$

Velocity at Minimum Sinking Speed.—Inserting the value of $K_L = .625$ in the equation $V^2 = \frac{W}{K_L . \rho . A}$ we get

$$V^2 = \frac{500}{.625 \times .0024 \times 200} = 1680$$

and V = 41 ft./sec. or 28 miles/hour.

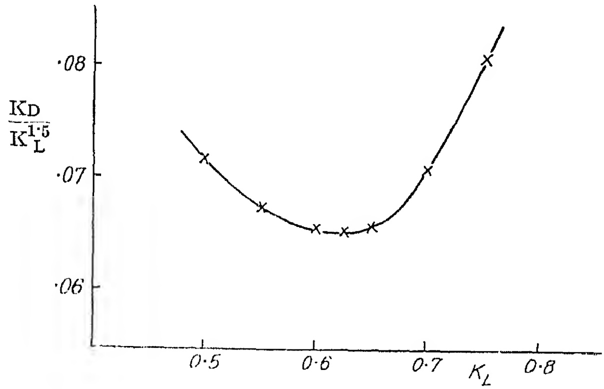


FIG. 21.

It will be noticed that the lowest sinking speed is only 3.5 miles/hour above stalling speed. This is the optimum speed for gaining height in an up-current.

Best Gliding Angle.—The best gliding angle has been shown in Fig. 19 to take place when $K_L = 0.53$. Hence, speed for

$$\text{best gliding angle} = \sqrt{\frac{W}{K_L \times .0024 \times A}}$$

$$= \sqrt{\frac{500}{.53 \times .0024 \times 200}}$$

= 44.25 ft./sec. or 30.2 miles/hour.

Sinking speed will then be

$20.4 \times \sqrt{\frac{500 \times 15}{(55)^2}} \times .0689$ (the value .0689 being obtained from Fig. 21 for $K_L = 0.53$)

$= 2.24$ ft./sec.

Therefore the gliding angle is such that $\sin \epsilon = 2.24/44.25 = .0506$ and $\epsilon = 2° - 54'$ or 1 in 20, say.

This gives the speed and angle of glide for obtaining maximum distance in still air.

CHAPTER III

MAIN PLANE LOADS AND FORCES

Load Curve—Bending Moment Diagrams for Flying and Landing Conditions—Reactions at Supports and Load Diagrams—Shear Forces—Distribution of Loads in Spars for C.P.F., C.P.B., and L.N.D. Conditions.

Load Curve

THE weight supported by the wings is equal to the total all-up weight less the weight of the wings themselves, since the wing weight has to be supported before any upward air load can be taken, or, in other words, the wings are subjected to an upward load equal to the total weight of the machine, and a downward load equal to the wing weight.

Hence nett load on wings $= W_{\text{total}} - W_{\text{wings}}$.

If this were spread uniformly over the total area, A, the loading per sq. ft. would be $\dfrac{W_{\text{total}} - W_{\text{wings}}}{A}$.

There is, however, a loss of lift due to the wing-tip effect, which consequently increases the intensity of loading over the inner portion. The load curve at the tips may be assumed parabolic over a length equal to the chord. This is not quite accurate, but owing to the small chords generally employed for sailplane wing-tips it is reasonably correct.

The equivalent loss in area may, therefore, be taken as $C^2/3$ where C = the mean tip chord, and the nett loading becomes

$$\frac{(W_{\text{total}} - W_{\text{wings}})}{(A - \frac{2}{3}C^2)}$$

With wings of parellel chord the load/ft. run over the inner portion becomes

$$\frac{W_{\text{total}} - W_{\text{wings}}}{C\,(A - \frac{2}{3}C^2)} \quad . \quad . \quad . \quad (1)$$

Fig. 22 (*a*) shows the curve of loading along the span and the effect of the end losses for a wing with parallel chord.

In the case of a tapering wing the load falls off towards the tips proportionately to the amount of taper.

Thus if, for example, a wing has an area of approximately 200 sq. ft. with a span of 55 ft. divided into three lengths of 18, 19 and 18 ft., with a parallel chord of 4′ 6″ over the middle

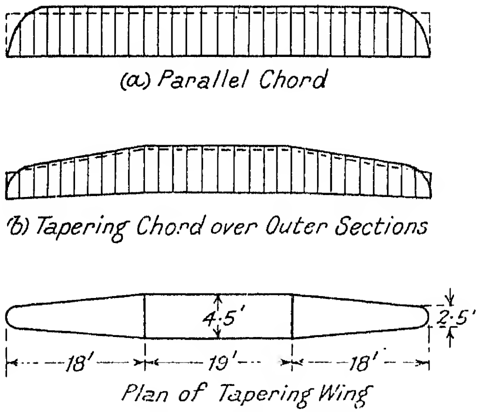


FIG. 22.—Loading Curves on Main Planes.

portion, and a straight taper to 2′ 6″ at the tips, the end losses can be taken as equivalent to an area of $\frac{2}{3}\times 2.5^2 = 4.17$ sq. ft.

Assuming a total load of 500 lbs. and wing weight 220 lbs., the nett loading becomes $\frac{500-220}{200-4.17}=\frac{280}{195.83}=1.43$ lbs./sq. ft.

The load/ft. run over the parallel portion will be 4.5×1.43 lbs $=6.44$ lbs./ft.

The chord over the tapering portion decreases from 4.5 ft. to 2.5 ft., or 2 ft. in 18 ft. $=0.111$ ft./ft.

Hence the load/ft. will decrease uniformly to within, say, 2.5 ft. from the tip, at the rate of $1.43\times 0.111=.159$ lbs./ft.

In this way the loads acting at every foot run of the span are found and may be denoted by w_1, w_2, w_3, etc.

Bending Moment Diagram—Flight Conditions

There are many different arrangements possible for supporting the main planes of sailplanes, added to which the form of loading must be taken into consideration. The more general cases only will be considered here.

1. Parallel chord, pure cantilever.
2. Parallel chord, semi-cantilever.
3. Tapering chord, pure cantilever.
4. Tapering chord, semi-cantilever.
5. Three supports and hinge joints at centre.
6. Two supports.
7. Four supports.

Case 1. Parallel chord, one central support only.—This is the simplest case, and the B.M. at any point, distant x from the tip, is $M = w_1 l_1 + w_2 l_2 \ldots w_x x$ . . . . . (1), where $l_1 - l_2 =$ the rib spacing.

If the loading is uniform the B.M. becomes

$$M = w(l_1 + l_2 + \ldots + x) = \tfrac{1}{2} wx^2 \quad . \quad . \quad . \quad . \quad (2)$$

The maximum B.M. occurs at the centre and is equal to

$$M_B = \tfrac{1}{2} ws^2, \text{ where } s = \text{span}/2.$$

If the end effect is to be allowed for, formula (1) must be used.

The B.M. curve is a semi-parabola with the vertex at the wing-tip and is illustrated in Fig. 23 (*a*).

Case 2. Parallel chord, three points of support.—As before, the B.M. at any point between the tip and the outer support

$$M = w_1 l_1 + w_2 l_2 + \ldots + w_x x \quad . \quad . \quad . \quad . \quad (3)$$

or if the loading is assumed uniform

$$= \tfrac{1}{2} wx^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The B.M. on the central spans is not so simple.

By the three moments equation, and assuming the spar section to be constant throughout the length between the outer supports: $M_A l_1 + 2 M_B (l_1 + l_2) + M_{A'} l_2 = \frac{w}{4}(l_1^3 + l_2^3)$.

And since the spans between supports are generally equal, i.e. $l_1 = l_2$, and M_A will equal $M_{A'}$ we get

$$2\,M_A l + 4\,M_B l = \frac{w}{2} l^3$$

or $2\,M_A + 4\,M_B = \frac{w}{2} l^2$ and $M_B = \frac{w}{8} l^2 - \frac{M_A}{2}$ . . . (5)

This means that the B.M. at the central support is equal to the difference between the maximum B.M. for a simply supported beam, of length equal to the distance apart of the supports, and half the B.M. at the outer support. If the latter quantity is larger than the former, the B.M. at the central support is of opposite sign to that of the outer supports.

So far the B.M. has been found for the outer section and at the central support. To obtain the B.M. on the inner bays set out the support B.M.s to some suitable scale (on opposite sides of the base line if of different sign) and join by straight lines. (See Fig. 23 (*b*).) Then set up the B.M. curve for each bay as simply supported beams subjected to uniform loading. These are parabolas with maximum co-ordinates at the centre equal to $wl^2/_8$.

The difference between the two sets of curves gives the B.M. between the supports.

Case 3. Tapering chord, one central support.—The B.M. at any point is $M_x = w_1\,l_1 + w_2\,l_2 + \ldots\ w_x . x$ . . . (6) and is maximum at the centre.

If the central portion of the wing is of parallel chord, the loading over that part is uniform, and then the B.M. at the centre is $M_B = \Sigma wl$ . . . . (7)

The B.M. curve is similar to Fig. 23 (*a*).

Case 4. Tapering chord, three points of support.—The B.M. in outer bays is found as in Case 2 and M_A is thus known.

If the span between the supports is of parallel chord and therefore is subjected to even loading, the B.M. curve over this portion is obtained in the same way as in Case 2, but if, as is unusual, the tapering continues to the centre or to a point within the supports, the B.M. curve may be found as follows :

The B.M. curve for the unevenly loaded bay is first obtained for a simply supported beam (Fig. 24).

Suppose the beam AB, of span l, is subjected to loads W_1, W_2, W_3 . . . W_n at equal spacing (the spacing of ribs is generally regular, and is taken as unity).

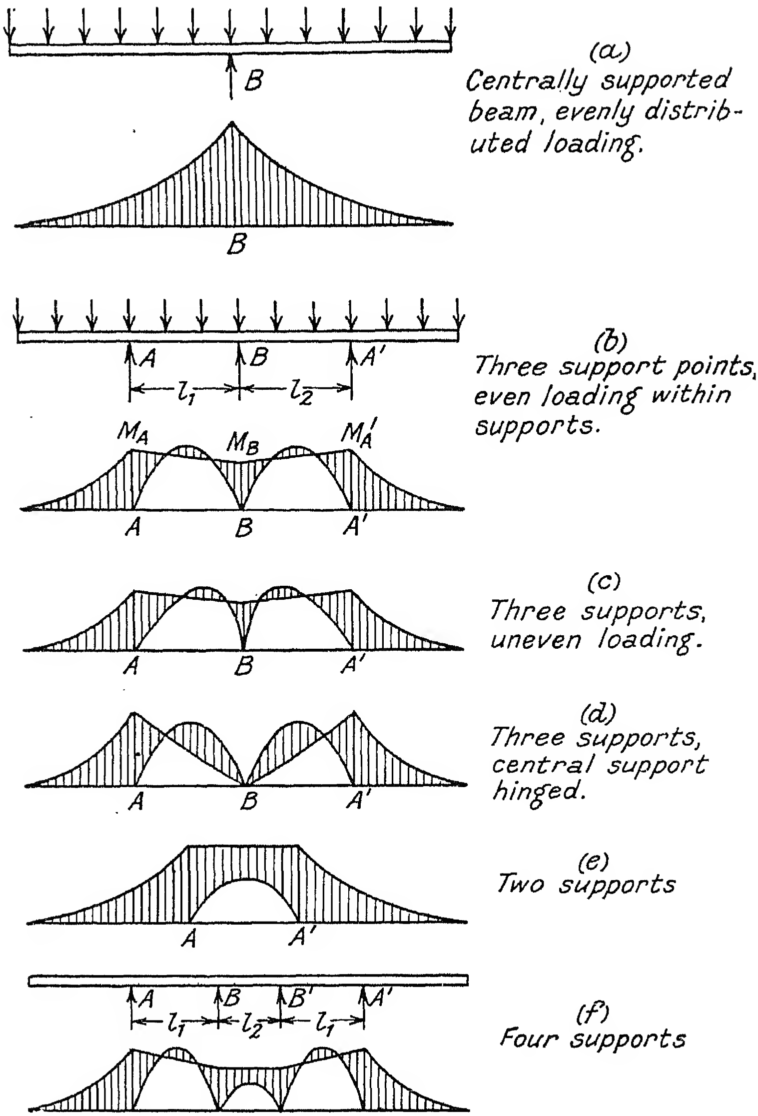


FIG. 23.—Bending Moment Curves for Various Main Plane Support Arrangements.

Then, by taking moments about B : $R_A l = W_1 l + W_2 (l-1) + W_3 (l-2) \ldots + W_{n-1}$.

Hence R_A is found, and R_B similarly.

Now the B.M. at any point x from A is

$$M_x = R_A . x - \left\{ W_1 . x + W_2 (x-1) \ldots . W_{x-1} \right\} . \quad (8)$$

By taking a series of points the bending moment curve is found as in Fig. 24.

Let the area under this curve be $\bar{A}$ and the distance of its centroid from A, $\bar{x}$.

Then for a continuous beam $M_B = \frac{3 A\bar{x}}{l^2} - \frac{M_A}{2}$ . . (9)

This value is set up as at B, Fig. 23 (c), and the diagram completed by adding the curves for simply supported beams, as found by formula (8) above, and joining the extremities of the support moment ordinates.

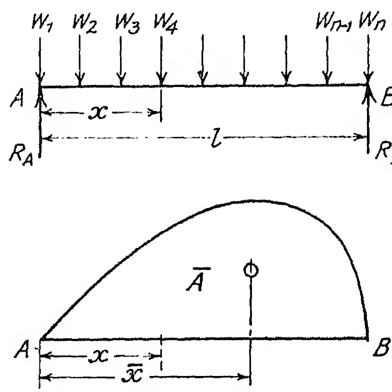


FIG. 24.—Bending Moment Curve for Unevenly Loaded Beam.

Case 5. Three supports, hinge joint at centre.—Where the central of three supports is made with hinged joints there can be no bending moment at the centre.

The case is similar to (2) and (4), but $M_B = O$.

Case 6. Two supports.—In this case the bending moment between the supports is reduced from that at the support points by an amount equal to the bending moment due to a simply supported beam of length equal to the distance apart of the supports. The central bay in this arrangement is generally quite small and the case may then be treated as Case 1.

Case 7. Four supports.—This is dealt with in a similar manner to Case 2, but there is an extra bay.

Where the central bay is very small the case may be

treated as Case 2, but otherwise M_B is found by the three moment equation thus :

$$M_A\, l_1 + 2\, M_B\, (l_1 + l_2) + M_A\, l_2 = \frac{w}{4}(l_1^3 + l_2^3).$$

The diagram is completed by adding the curve over each bay for simply supported spans.

There are other cases that may be formed by combinations of the above, but they can all be solved with the aid of the cases described.

It should be noted that where the cross section of the spars is not constant between supports some modification is necessary. Particular care should be exercised regarding the signs of the support moments and the values set off above or below the base line accordingly.

Landing Load Bending Moments

The bending moment curves for the landing condition are similar to those for flying loads but of reversed sign. The loads are those due to the weight of the wings.

It has been shown, in Chapter II, that the wing weight is generally in the neighbourhood of 1 lb./sq. ft., and since the nett flying loads are about 1.5 lbs./sq. ft., the intensity of bending moment for landing will be roughly two-thirds that for flight. A higher factor is generally employed for the landing condition, but if the spars are of symmetrical section, about the horizontal axis, this condition is usually covered by the requirements of flight conditions.

Reaction at Supports and Load Diagrams

Where the main plane is supported at more than one point the reaction at the points of support have to be found.

The reaction at B, R_B (Fig. 23 (*b*)) $= R_{BL} + R_{BR}$

$$\text{where } R_{BL} = \frac{w \cdot l_1}{2} + \frac{M_B - M_A}{l_1}$$

$$\text{and } \quad R_{BR} = \frac{w \cdot l_2}{2} + \frac{M_B - M_{A'}}{l_2}$$

For the reaction at the outside support, R_A, the value of

R_{AL} = total load to left of A.

The reactions are thus found for every point of support.

The reactions at the main supports having been found a load diagram can be drawn, Fig. 25, to some suitable scale, by setting off *ab*, *bc*, *cd*, etc., to represent the support loads, and completed as shown.

The loads in all the members—spars, struts, etc.—are thus found by measurement of the load diagram.

The load, *be*, in the spars is a compressive end load, and has to be added to the bending moment load. With single support arrangements there is no end load in the spars to be taken into account.

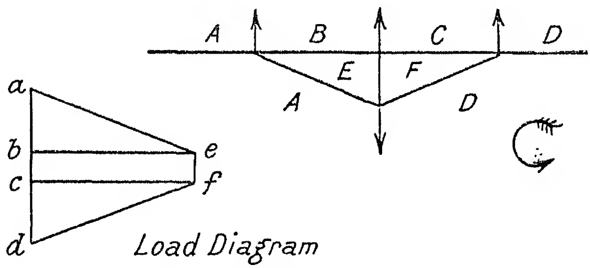


FIG. 25.—Main Truss Load Diagram.

If the figures obtained from the load diagram are multiplied by $\frac{\text{Landing Load Factor}}{\text{Flying Load Factor}} \times \frac{\text{Wing Weight}}{\text{Loaded Body Weight}}$, the corresponding loads for landing conditions are found.

The struts, A E and F D, are subjected to tension loads in the flying case and compressive loads in the landing condition.

Shear Forces

(*a*) The *direct shear loads*, at any point, in cantilever wings is equal to the total load between that point and the wing-tip.

Where there are more support points than one the shear force curve is obtained by adding the air loads along the span from the wing-tip to the first support. Here the support reaction load is subtracted, and the air loads commence to accumulate again.

Diagrams for various support arrangements have been shown in Fig. 26. With tapering wings the shear force curve

is not a straight line, but gets steeper as the chord increases and also, owing to end effect losses, the curve near the wing tips should be modified slightly. This latter effect is negligible for sailplane work and can be ignored.

(*b*) There is also a *horizontal shear load* in the spars tending to slide the lower half of the spar away from the upper half in a sideways direction. The maximum horizontal shear stress is at the natural axis, and is $f_S = \frac{S A \bar{y}}{I t}$

where S = vertical shear force.

$A\bar{y}$ = first moment of half the spar section about the neutral axis.

I = moment of inertia of full section, and

t = thickness of spar at neutral axis.

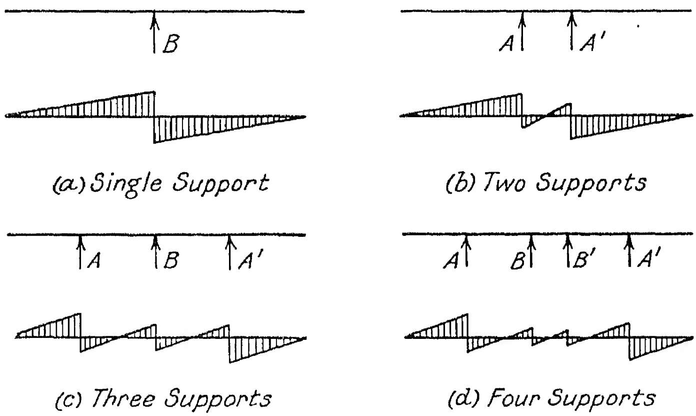


FIG. 26.—Shear Force Diagrams for Various Main Plane Support Arrangements.

Secondary Failure

Secondary failure is brought about by the end loads in the main spars, set up by the tension load in the lift struts, causing the spars to fail together in the plane of the wing.

This is not of great importance in sailplane design and obviously can only take place in strutted wings. Most sailplanes include a plywood covering over the leading edge for torsional resistance, for retaining the correct profile shape or for rigidity, and this stiffening provides a sufficiently large lateral moment of inertia to prevent secondary failure.

Where there is no stiff covering over the wing surface the possibility of lateral failure should be gone into.

In Fig. 27 the main plane is shown divided into drag bays by struts AA^1, BB^1 and CC^1. Then the critical load is, by Euler,

$$Q = \frac{\pi^2 E\,(I_F + I_R)}{l^2},$$

where I_F and I_R are the lateral moments of inertia of front and rear spars respectively, and l=span of drag bay.

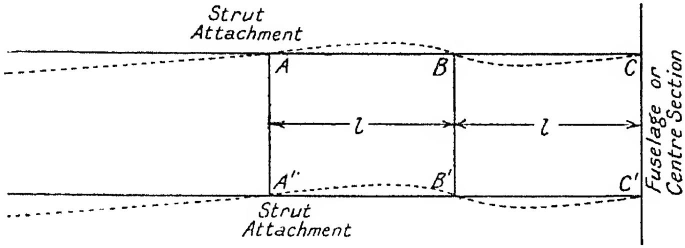


FIG. 27.—Secondary Failure.

Drag Loads

In normal flight a sailplane is descending through the air at a small angle to the horizontal, due to the component of the machine's weight in that direction. This weight component is made up of the wing weight component and the fuselage or body weight component.

For steady flight this force in the direction of flight is equal and opposite to the resistance of the wings and body.

The weights of wings and body are fairly equal, whilst the wing resistance is generally rather greater than the body resistance, so that a small drag load is usually present in the wing structure.

As the dive becomes steeper and the speed increases the wing drag component becomes more nearly equal to the body component and therefore the amount of drag stresses in the wing structure decreases.

In other words the wing is at or near its least drag position and is being pulled down by its own weight.

From this it is seen that drag is of little importance in the design of sailplane wings, and is easily taken by the plywood covering over the leading edge. It will be noticed that as

the C.P. moves back the torsion load increases, whilst the drag load decreases.

DISTRIBUTION OF LOADS IN SPARS FOR C.P.F., C.P.B., AND L.N.D. CONDITIONS.

1. Single Spar Wings

When a single spar only is used, it is generally placed at, or very close to, the C.P.F. position and therefore takes the full load as a direct bending load.

For C.P.B. the bending load is less owing to the employment of a smaller factor, but there is also a torsion load set up, equal to the total load multiplied by the distance of the C.P.B. position to the spar. This torsion load must be combined with the bending load if the spar is designed to take both loads.

Thus if the stress due to bending is denoted by p and the torsion stress by f_t,

The maximum shear stress is $\sqrt{{}^1/_4\, p^2 + f_t^2}$,

and maximum direct stress is ${}^1/_2\, p + \sqrt{{}^1/_4\, p^2 + f_t^2}$.

When a torsion tube is used with the spar, the former resists the torsional load, and the latter takes bending loads only.

In the limiting nose dive there is a large torsional load on the wing and a very small lift force. The torsion tube should be capable of carrying the whole of the torsion and the bending load may be neglected unless there is no torsion tube, in which case the main spar must be designed to withstand both loads, as in the C.P.B. case.

2. Two-Spar Wings

For C.P.F. the front spar takes $\frac{l-a}{l}$ of the total load, W, Fig. 28, and the rear spar a/l of the total load, whilst for C.P.B. the front spar load is b/lW and the front spar $\frac{l-b}{l}$W.

Moving the rear spar forward generally allows the use of a deeper spar, but it is brought closer to the C.P.B. position, and therefore takes more load in this condition. The best position should be found.

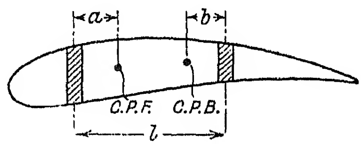


FIG. 28.—Spar Loads in Two-spar Wing.

For the L.N.D. condition there is an upward load on the rear spar and a downward load on the front spar.

In Fig. 29, by moments about the front spar,

$$P_R = \frac{P_T l}{a} \text{ and } P_F = P_R - P_T.$$

This method of finding the spar loads is only approximate, and for a more accurate method the reader is referred to A.P. 970.

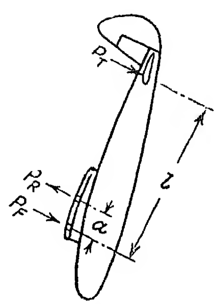


FIG. 29.—Spar Loads in Limiting Nose-dive.

CHAPTER IV

Design of Main Planes

Spar Arrangement—Spar Sections—Unsymmetrical Spar Sections—Strength of Spars—Main Plane Ribs—Lift Struts—Examples of Main Plane Calculations for Cantilever and Braced Types.

Spar Arrangement

THERE are three chief arrangements for the main plane spars of sailplanes :

1. One spar and torsion resisting nose.
2. Two spars, with or without torsion tube, and
3. One main spar with torsion tube and secondary spar.

With the single spar arrangement, the spar is placed at, or very close to, the position of the centre of pressure for the forward condition and a stiff plywood covering passes from above the spar, forward round the leading edge, and back to the underside of the spar. As the C.P. moves towards the trailing edge a torsional load is imposed on the plane and this is resisted by the leading edge covering. This is a favourite method in sailplane design. (See Fig. 30 (*a*).)

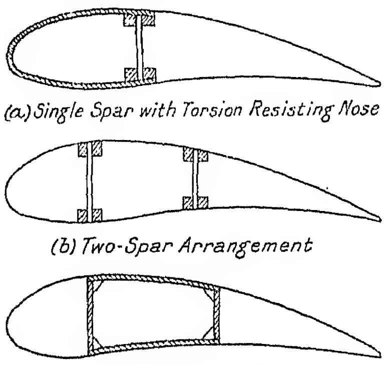


FIG. 30.—Spar Arrangements.

When two spars are employed they are generally placed outside the C.P.F. and C.P.B. positions so as to equalize the loads on the spars, as far as practicable, during normal flight. Fig. 30 (*b*).

In the third method the secondary spar acts as a support for the ailerons, shortens the unsupported distance of the main ribs and generally stiffens the structure.

There are other arrangements such as single spar, without nose strengthening, in which the spar takes both bending and torsional loads, three spars, or multi-spar, and also modifications of the methods outlined such as (*c*), Fig. 30. This could be considered as a single box spar or alternatively as two spars with torsional covering.

Another useful alternative employs a torsion resisting nose, together with a light secondary spar, but instead of anchoring the root leading-edge to the centre section, the plywood covering is taken back to the rear spar, as shown in Fig. 31, so that the torsion is transmitted through both spar attachment fittings. A diagonal member runs from the front spar back to the rear spar fitting to complete the torsion box.

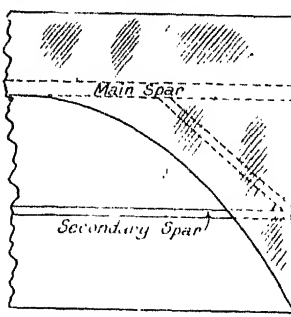


FIG. 31. Torsion Device for Main Plane.

The multi-spar arrangement offers possibilities and has been used, but the wing suffers from lack of rigidity and consequent undue deflection.

The large box-spar, Fig. 30 (*c*), can be made to form part of the wing with suitable nose and tail attachments. It may be designed so that the webs take the bending moment and the flanges take the torsion, or the flanges can be made to take both bending and torsional loads. One advantage of this arrangement is that the flange plies may decrease in thickness towards the tip. Large tubular structures of this sort must be suitably strengthened at fairly close intervals, equal, say, to the rib spacing, or collapse of the walls will take place long before the maximum stresses of the material are reached.

The use of a torsion resisting wing nose has the great advantage of providing at the same time a good aerodynamic shape over the most important part of the aerofoil, besides which a robust structure results, which is of great value for handling and storage purposes.

Spar Sections

Fig. 32 shows the most common sections used in sailplane design.

The first, (*a*), consists of a single vertical web. It is the cheapest to produce, but is uneconomical and is only used for machines of small span.

The second, or I, section illustrated, (*b*), is the one mostly used and consists of halved spruce flanges glued to a plywood web. It provides a very suitable spar and is relatively cheap. The spindled " I " section spar is seldom or never used in sailplane design.

The box spar is shown in (*c*), consisting of spruce flanges faced with plywood webs. This is a more efficient section than (*b*) and has much better torsional resisting qualities,

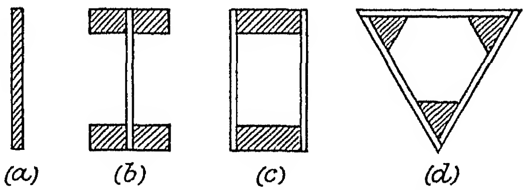


FIG. 32.—Spar Sections for Main Planes.

but is rather expensive and needs considerable care in manufacture.

The triangular spar, (*d*), has been favoured by some British designers. If placed with the apex at the bottom, some saving of material may be effected owing to the allowable tension stresses in timber being greater than the compression stresses. This advantage is, however, reduced by the fact that the timber at the apex is not concentrated as far from the neutral axis as it could be with other shaped sections.

Sections (*b*) and (*c*) are also used with the bottom flanges of less depth than the top, although, as pointed out previously, the difference between flying and landing loads is not always very great.

The triangular section does not lend itself so easily for the attachment of fittings.

Sections (*c*) and (*d*) can be made to resist the torsional loads as well as bending, but the first two shapes generally need extra stiffening against torsion and secondary failure.

Unsymmetrical Spar Sections

The strength of spruce in tension is approximately twice that in compression, the allowable figures being 9,000 and 4,500 lbs./sq. in. respectively.

For this reason spars are often made with larger compression flanges than tension flanges, and if loading is in one direction only, say upwards for normal flight, the most economical section would be one in which the centroid is twice the distance from the extreme tension fibres as it is from the compression edge. (See Fig. 33.)

This is explained as follows: If the allowable tensile stress is denoted by p_t, the compression stress as p_c and $p_t = 2p_c$,

$$\text{We have } p_t = \frac{My_2}{I} \text{ and } p_c = \frac{My_1}{I}$$

or, since M and I are constant, p is directly proportional to y, hence $y_2 = 2y_1$.

It should, however, be noted that the full benefit of this weight saving is not, usually, available owing to the tension flange being put into compression by a reversal of loading.

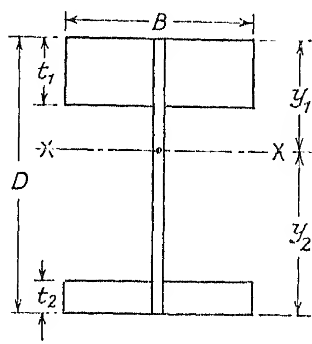


FIG. 33.
Unsymmetrical Spar Section.

For example, if a spar is to be designed for a C.P.F. factor of 6, and the sailplane weight is made up of 40% due to the wing and 60% body weight, then the load supported, multiplied by the factor, is $0.6 \times 6 \times W = 3.6$ W.

If a factor of 8 is allowed for landing conditions, taking the wing weight as load, then the factored load becomes $0.4 \times 8 \times W = 3.2$ W.

The bending moments for the two conditions will be approximately in the proportion of 36 to 32 and the weight saving, in this case, is only small.

If the bending moment for normal C.P.F. flight is denoted by M_n and for landing M_l, then $M_l = 32/36\ M_n$, assuming the wing weight is distributed in proportion to the air loading, which is not strictly correct.

To satisfy these conditions, $M_u = p_c . I/y_1$, and

$$32/36\ M_u = p_c . I/y_2 \text{ or } \frac{p_c . I}{y_1} = \frac{p_c . I . 36}{y_2\, 32},$$

where p_c = allowable compressive stress.

The tensile stress has not been considered, as in both cases of loading it will be well within the maximum allowable.

Hence $y_1 = 32/36 \times y_2$.

In general, the moment of inertia of such a section neglecting the web is:

$$\frac{B}{3}\left[\left\{y_1^3 - (y_1 - t_1)^3\right\} + \left\{y_2^3 - (y_2 - t_2)^3\right\}\right],$$

Also,

$$y_2 = \frac{t_2^2/2 + t_1\ (D - t_1/2)}{t_1 + t_2} \text{ and } y_1 = D - y_2.$$

Strength of Main Plane Spars

In Chapter III it was seen that the main spars have to be considered for the loading conditions due to C.P.F., C.P.B., and L.N.D., and that the forces to be calculated for are those due to bending; torsion; shear, both vertical and horizontal; end load; and secondary bending due to end load.

In the case of cantilever wings the spar strength should be calculated for a series of points, say at every one-eighth span. With braced wings the spars should be checked at each point of support, every mid-bay position, and any other points of importance.

Resistance to Bending.—The bending moment diagrams are drawn out for the whole wing and the values obtained are multiplied by the C.P.F. factor in the case of single-spar machines. For two-spar wings the B.M. values are multiplied by the percentage factor for each spar and the loading factor.

Generally the front spar may be considered for C.P.F. and the rear spar for C.P.B.

Thus if the percentage factor for C.P.F. on the front spar is 75% and the loading factor 6, then the B.M. values should be multiplied by 0.75×6 or 4.5.

The maximum bending stress in a spar is $p = \frac{My}{I}$; where M is the bending moment, p = distance of extreme fibre from

neutral axis, = half depth for a section symmetrical about the horizontal axis, and I = the moment of inertia of the section.

Resistance to Shear.—It is assumed that the vertical shear is taken by the spar web or webs and the shear stress is therefore S/A_w.

The maximum horizontal shear stress was given in the last chapter as $f_s = \frac{S A\bar{y}}{It}$; where $A\bar{y}$ = the first moment of half the spar above the neutral axis about that axis.

Resistance to Torsion.—Where torsion is the only load to be considered the stress may be found by the following formulæ:

For hollow circular section of thin material, thickness t, and mean radius, r.,

$f_t = \frac{T}{2\pi r^2 t}$, where T is the torque load

For a solid rectangle $f_t = \frac{T}{ab^2}(3 + 1.8\frac{b}{a})$, where a is length of long side and b is length of short side and occurs at the middle of side a.

For any hollow section of thin material, $f_t = \frac{T}{t(A + A^1)}$ where A is the outside area and A^1 the inside area, or for very thin material $= \frac{T}{2tA}$.

Combined Bending and Torsion.—Where any one member is subjected to bending and torsional loads acting at the same time the stresses due to each loading separately have to be found as explained above, and combined in the formulæ as follows:

$$\text{Max. shear stress} = \sqrt{{}^1/_4\, p^2 + f_t^2} \text{ and}$$

$$\text{Max. direct stress} = {}^1/_2\, p + \sqrt{{}^1/_4\, p^2 + f_t^2}.$$

Main Plane Ribs

The types of ribs are explained and discussed in Part II, Chapter X. The spacing is generally made 1 ft., which is very suitable and simplifies the calculations. Greater spacing than this allows the fabric to sag between the ribs. There is generally one intermediate rib, and sometimes two, between the main ribs.

Ribs are generally built-up girders of rectangular sectioned booms and struts, although sometimes plywood webs take the place of the diagonal strut bracing.

With the girder type the necessary sizes of members can be found by means of a load diagram, although this is not very accurate for members of such small cross section and they are more often designed on experience and, where possible, tried out by loading tests.

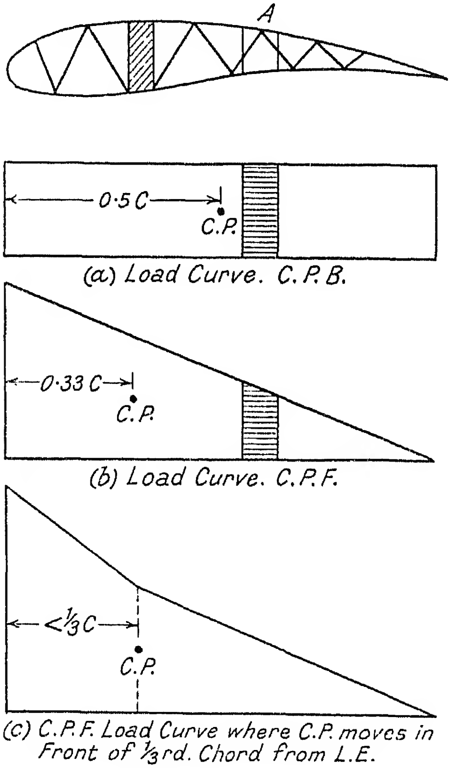


FIG. 34.—Distribution of Air Loads on Rib.

In order that the wings shall not be unduly frail, sections for booms and struts are seldom made less than $\frac{1}{4}'' \times \frac{3}{16}''$, although sections as small as $\frac{3}{16}'' \times \frac{1}{8}''$ have been employed.

Such light ribs are liable to be easily damaged and the total saving on the whole wing is very little, so that it is very doubtful whether the use of such frail ribs is worth while.

Ribs should be designed for C.P.F. and C.P.B. and checked for inverted flight, if called for.

The loading per rib is found (Chapter III) and is assumed to be uniform for C.P.B., i.e. the load diagram is rectangular.

For C.P.F.' the load is assumed triangular if the C.P.F. position is at about one-third chord from the leading edge, but if the C.P. moves forward to, say, 0.25 chord, a modified load diagram is necessary, as shown in Fig. 34 (*c*).

If the total load on the rib is p lbs. and the chord is n

inches, then the loading for C.P.B. is p/n lbs./in. and for C.P.F. is $2p/n$ at the leading edge, decreasing uniformly to nil at the trailing edge. These values must be multiplied by the load factor.

The loads at all rib nodes are found. The load at each joint, say A, Fig. 34, can be taken as the area of the load curve extending half-way to the next joint on both sides.

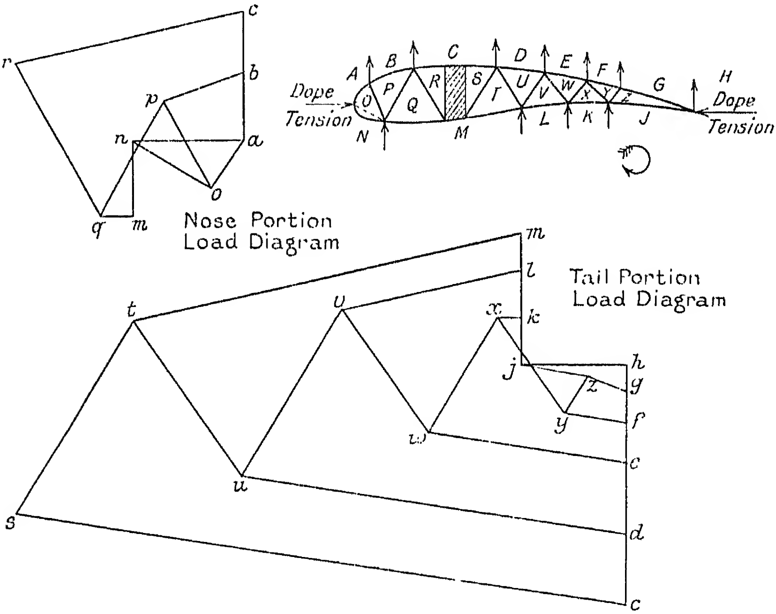


Fig. 35.—Rib Load Diagrams.

In this way the loads acting along the rib are found, those acting directly at the spar, or spars, can be ignored.

If the wing is fabric covered horizontal loads at the leading and trailing edges due to the dope tension must be included. The fabric tension load may be taken as 3 lbs./in. run with a factor of 1.

Fig. 35 shows typical load diagrams for a rib. Separate diagrams are drawn for the nose and tail portions, and in the case of two-spar wings a third diagram will be necessary.

It will generally be found sufficient to stress the nose portion for C.P.F. and the tail for C.P.B.

Lift Struts

Sailplane struts are generally of the following types:

1. Composite timber.
2. Steel or duralumin tubes.
3. Solid timber.

These are shown illustrated in Fig. 93 on page 135.

The first type is mostly favoured as it is very suitable for this kind of work where a long strut of extreme lightness is required, besides which it is cheap to produce.

The central spruce member prevents failure about the longitudinal axis of the section, and the ply covering stiffens the strut about the short axis.

Metal tubes of circular section are sometimes used and are faired off by plywood over formers. Streamlined metal tubes are seldom used on account of cost.

The last type, solid streamlined timber, is seldom used on account of the excessive weight.

Most sailplane struts are rather long with high values of L/K, where L=length and K=least radius of gyration, and Euler's formula for crippling loads for pin jointed struts is fairly accurate. This is $P = \frac{\pi^2 E I}{L^2}$.

Owing, however, to the fact that struts are seldom of absolutely uniform section and also there is generally some eccentricity of loading the limiting load is less than the Euler load.

There are several formulæ devised to make allowance for these factors, of which that due to Major Robertson has been found to give very satisfactory results, and this should be used for L/K values less than 130.

Curves for spruce struts calculated by Robertson's formula are given in Appendix VII, page 257.

Main Plane Calculations—Examples

In order to illustrate how the spar section sizes are determined a few examples are given below.

Case 1. *Pure cantilever wing, single spar placed at C.P.F. position. Chord constant over middle third, thence tapering to the tip.*

Assume that the bending moments and shear forces have been found and are as follows:

Spar Position.	*M lbs. ins.*	*S lbs.*
(*a*) At centre section . . .	22,000	150
(*b*) 1/12th span from centre . .	14,400	120
(*c*) 1/6th span from centre . .	8,500	90
(*d*) 1/3rd span from centre . .	2,000	36

For C.P.F. these figures should be multiplied by factor 6.

(*a*) *Centre Section.*—If spar section at the centre is 9″ deep and the width is chosen as $2\frac{1}{2}''$ with spar flanges $1\frac{1}{2}''$ deep, spruce,

$$\text{then } I = \frac{b}{12}(D^3 - d^3)$$

$$= \frac{2.5}{12}(9^3 - 6^3)$$

$$= 106.8 \text{ in.}^4$$

$$\text{and } p = \frac{My}{I} = \frac{22{,}000 \times 6 \times 4.5}{106.8}$$

$$= 5{,}560 \text{ lbs./sq. in.}$$

As the allowable working stress of spruce in bending is 5,500 lbs./sq. in. this section is slightly weak.

For rigidity the web width should not be less than 1/60th of the unsupported length. The distance between the inside of flanges is 6″, and therefore the webs should not be less than 6/60 = 0.1″ and may be of, say, $\frac{1}{8}''$ plywood.

The web must now be checked for shear.

Vertical shear: Area $6'' \times \frac{1}{8} = 0.75$ sq. in., load 150 lbs.,

and shear stress is therefore $\dfrac{150 \times 6}{0.75} = 1{,}200$ lbs./sq. in.

Longitudinal shear: $f_s = \dfrac{S A \bar{y}}{I t}$,

$$A = 2.5 \times 1.5 = 3.75$$

$$\bar{y} = 4.5 - 0.75 = 3.75$$

$$\therefore f_s = \frac{150 \times 6 \times 3.75 \times 3.75}{106.8 \times 0.125}$$

$$= 948 \text{ lbs./sq. in.}$$

The shear stresses are well within the allowable values.

(*b*) 1/12*th Span from Centre.*—M=14,400 lbs. in., S=120 lbs.

Outer dimension $9'' \times 2\frac{3}{8}''$. If flanges made $1''$ deep:

$$I = \frac{2.375}{12}(9^3 - 7^3) = 76.4 \text{ in.}^4$$

$$p = \frac{14{,}400 \times 6 \times 4.5}{76.4} = 5{,}090 \text{ lbs./sq. in.}$$

If the web thickness remains constant there is no need to check the vertical shear.

Horizontal shear stress:

$$fs = \frac{120 \times 6 \times 2.375 \times 4}{72.4 \times 0.125} = 715 \text{ lbs./sq. in.}$$

(*c*) 1/6*th Span from Centre.*—M=8,500 lbs. in. and S=90 lbs.

If outer dimensions are $9'' \times 2\frac{1}{4}''$ and flanges are made $\frac{3}{4}''$ deep, then

$$I = \frac{2.25}{12}(9^3 - 7.5^3) = 57.75 \text{ in.}^4$$

$$\text{and } p = \frac{8{,}500 \times 6 \times 4.5}{57.75} = 3{,}980 \text{ lbs./sq. in.}$$

Horizontal shear:

$$fs = \frac{90 \times 6 \times 1.686 \times 4.125}{57.75 \times 0.125} \qquad A = 2.25 \times .75 = 1.6875$$

$$= 522 \text{ lbs./sq. in.} \qquad \bar{y} = 4.5 - 0.375 = 4.125$$

(*d*) 1/3*rd Span from Centre.*—M=2,000 lbs. in. S=36 lbs.

Assuming the spar has tapered to a depth of $6''$ and trying $\frac{1}{2}''$ flanges:

$$I = \frac{2.25}{12}(6^3 - 5^3)$$

$$= 17.06 \text{ in.}^4$$

$$\text{and } p = \frac{2{,}000 \times 6 \times 3}{17.06} = 2{,}110 \text{ lbs./sq. in.}$$

This figure is low and some modification of the spar size might reasonably be made.

When all the sections have been thus calculated, a drawing can be prepared, Fig. 36. It should be noted that the shape of flanges should comply with the profile of the aerofoil at the

spar position and allowance will have been made for the depth of rib flanges and ply covering, if used.

Torsion.—Assume a maximum torsion value of 40,000 lbs. in. or 20,000 lbs. in. each plane. If leading edge tube

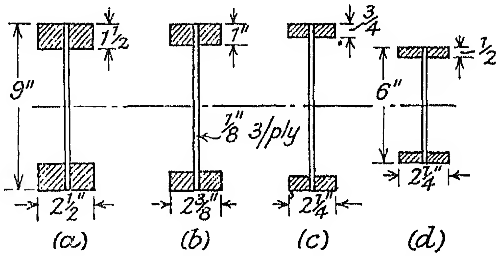


FIG. 36.—Main Plane Spar Sections.

thickness is 2 mm. or 0.08″, and an equivalent diameter of 12″ can be assumed, then

$$f_t = \frac{T}{2\pi r^2 t} = \frac{20{,}000}{2\pi \times 36 \times 0.08} = 1{,}100 \text{ lbs./sq. in.}$$

This would be satisfactory if ply is laid on with the grain of outer ply either parallel to or perpendicular to the spar, but if it is laid so as to make an angle of 45°, a decrease in thickness would be allowable.

The torsion decreases towards the tips and consequently the plywood thickness could be reduced away from the centre.

The C.P.B. case, in which both bending and torsion are present, has not been considered. As, however, the bending will be only two-thirds of the amount for C.P.F. and the torsion will be less than for the L.N.D. case, and if it is assumed that the leading edge torsion tube takes all the torsion and the spar the bending moment, then there is no need to check for C.P.B. with this design.

The spars may be checked for inverted flight or landing conditions if considered necessary.

Case 2. Semi-cantilever wing, two spars, lift strut attached at 1/6th span from centre.

Assuming a main plane of similar shape and area as for Case 1, and spar positions at 18% and 65% from the leading edge in a 4′ 6″ chord, with centre of pressure limits of 30% and 55% for C.P.F. and C.P.B., respectively.

Then maximum load coefficient on front spar is for C.P.F. and is $\frac{47-12}{47}$ or 74.5%. (See page 51, Chapter III.) And maximum load coefficient on rear spar is for C.P.B. and is $\frac{47-10}{47}$ or 78.8%.

Multiplying these values by the required factors for C.P.F. and C.P.B. gives the figures by which the unit bending moment and shear loads must be multiplied.

Hence front spar factor becomes $0.745 \times 6 = 4.47$ and rear spar factor becomes $0.788 \times 4 = 3.152$.

The spar bending moments at the lift strut attachment point are therefore $4.47 \times 8{,}500 = 38{,}000$ lbs. in. and $3.152 \times 8{,}500 = 26{,}750$ lbs. in., for front and rear spar, and the sections can be calculated as for Case 1.

The central B.M., $M_B = \frac{w}{8} l^2 - \frac{M_A}{2}$ . . . Chapter III, formula (5), page 43, and if the values of $w = 6.75$ lbs./ft. run and $l = 9$ ft. are used, then

$$M_B = \frac{6.75 \times 81 \times 12}{8} - \frac{8{,}500}{2}$$
$$= -3{,}430 \text{ lbs. in.}$$

The B.M. curve as a simply supported beam gives B.M. at mid-bay, $M = \frac{wl^2}{8} = \frac{6.75 \times 81}{8} = 68.4$ lbs. ft. or 821 lbs. in.

The true bending moment at mid-bay position will be

$$\frac{M_A + M_B}{2} - M = \frac{8{,}500 + 3{,}430}{2} - 821 \text{ or } 5{,}145 \text{ lbs. in.}$$

and multiplying by the front and rear spar factors gives the bending moments on each spar.

The support reactions are now required. The outer supports are:

$$R_A = R_{AL} + R_{AR}$$
$$R_{AL} = 90 \text{ lbs. and}$$
$$R_{AR} = \frac{wl}{2} + \frac{M_A - M_B}{l}$$
$$= \frac{6.75 \times 9}{2} + \frac{8{,}500 + 3{,}430}{9 \times 12}$$
$$= 77.4 \text{ lbs.}$$

140·4 lbs

230.4 lbs

Hence $R_A = 90 + 77.4 = 167.4$ lbs.

Also $R_B = R_{BL} + R_{BR}$, or in this case, owing to symmetry,

$$= 2\,R_{BL}$$

$$R_{BL} = \frac{wl}{2} + \frac{M_B - M_A}{2}$$

$$= \frac{6.75 \times 9}{2} + \frac{-3{,}430 - 8{,}500}{9 \times 12}$$

$$= -\cancel{16.6}\text{ lbs.} \qquad -79.6\text{ lbs}$$

and $R_B = 2\,R_{BL} = -\cancel{33.2}$ lbs. $\quad -159.2$ lbs

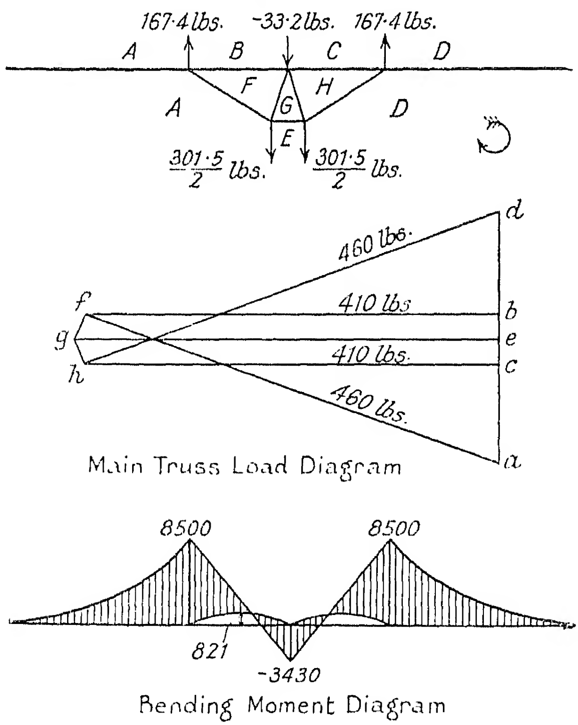


FIG. 37.—Main Truss Load and Bending Moment Diagrams.

Checking, $2\,R_A + R_B$ should = total weight less wing weight.

$$= 334.8 - 33.2$$

$= 301.6$ lbs. and this agrees fairly well, the assumed load being $6.75 \times 18 + 2 \times 90 = 301.5$ lbs.

It is now possible to draw the bending moment diagrams and load diagrams for the main truss system, using the loads found. A suitable arrangement at the centre section can be assumed.

This has been done in Fig. 37, from which the end loads in the spars and the strut loads are found.

The bending moment over the inner bays is increased to some extent beyond the values found already owing to the combined effect of the end load and the deflection of the spars.

This extra bending moment will be a maximum near the centre, or in this case a little distance beyond the centre towards the tip, owing to the larger primary bending moment there causing greater deflection.

It will be noticed from the bending moment diagram, Fig. 37, that the value at the outer support is far greater than at the centre, and it is almost certain that the spar sections at the centre, owing to their considerable depth, will give a far greater margin of strength than is required, and this extra margin will most likely diminish towards the outer support.

The end load present in the spars is not a great amount and the strength margin explained above can generally be relied upon to compensate for this. The spars are strengthened again by the torsion tube, and it will be noted that, as the torsion load on this member increases, so the end load on the spars will decrease.

If, however, it is considered necessary to calculate the bending effect of the end load accurately the method given in A.P. 970 [1] should be applied.

Secondary Failure

The end load on the spars is 410 lbs. and multiplying by factor 6 gives 2,460 lbs.

The failing load, $Q = \dfrac{\pi^2 E (I_F + I_R)}{l^2}$

and if the values of the moments of inertia for the spars are $I_F = 1.66$ in.^{4} and $I_R = 1.20$ in.^{4}, E for spruce is taken as 1,500,000 lbs./sq. in., and drag bays are 36 in. long, then

[1] A. P. 970, Chapter III, para. 5–7, Appendix IA, para. 6 and Appendix III.

$$Q=\frac{\pi^2\times 1{,}500{,}000\ (1.66+1.20)}{36\times 36}$$
$$=32{,}600 \text{ lbs.}$$

This shows that secondary failure need hardly be checked for this type of machine.

Again, when the leading edge, forward of the front spar, is ply-covered, the tendency for secondary failure is overcome by the leading edge covering.

Torsion Effect

If a value of 14,300 lbs. in. each plane is assumed for maximum torsion in the nose dive case, this having been calculated by the methods explained in Chapter III, then an up load will be placed on the rear spar and a down load on the front spar.

The rear spar load, by moments about the front spar, will equal the torsion divided by the spar spacing,

$$\text{or } F_R=\frac{14{,}300}{0.47\times 54}=563 \text{ lbs.}$$

Now the rear spar load for C.P.B. condition was equal to the nett load on one wing multiplied by the rear spar factor

$$=\frac{322}{2}\times 3.152=507 \text{ lbs.}$$

This means that the rear spar is subjected to slightly higher loading for the torsional case than in the C.P.B. case and the spar section could be increased proportionately, or, alternatively, a stiff leading edge covering could be used to help resist the torsion.

The front spar down load will be equal to the rear spar up load less the tail load, or say 370 lbs.

The up load on this spar for C.P.F. is $\frac{322}{2}\times 4.47=720$ lbs.

In most designs the spar resistance to down load is equal, or nearly equal, to that for up load, and therefore the down load due to torsion is well covered, but as the front main lift strut will be subjected to a compression load for L.N.D. conditions it should be designed to carry this.

Inverted Flight

The conditions are assumed similar to those for C.P.F. with a factor of 3 called for instead of 6. The B.M. and shear force curves will be similar, and unless spars of unsymmetrical section are used there is no need to check this case for the spars. The strut loads (compressive) will be those found from the load diagram, Fig. 37, multiplied by the factor 3.

Landing

The load during landing is that due to the wing itself, and as its weight is not likely to be more than the nett air loading for flight conditions, this case is very similar to the previous case.

Using a wing weight figure of 0.95 lbs./sq. ft. (see Chapter II) and a nett flying load of 1.5 lbs./sq. ft., it is seen that landing loads with a factor of 4 are well covered by inverted flight loads with factor 3.

Lift Struts

In C.P.F. and C.P.B. the lift struts are subjected to tension loads; in L.N.D. the front strut is in compression and the rear strut in tension; whilst for inverted flight and landing both struts are in compression.

The maximum tension for the front strut in this case will be for C.P.F. and for the rear strut in L.N.D., whilst the maximum compressive loads will be during L.N.D. for the front and for inverted flight on the rear strut.

The following table shows the values of the maximum loads on the struts in the different conditions of loading for the design considered.

From the table it is seen that the maximum factored loads on the front strut are 2,060 lbs. tension and 1,030 lbs. compression, and on the rear strut 1,450 lbs. tension and 350 lbs. compression.

Design of Front Strut

Suppose a composite strut of spruce and plywood 96″ in length is to be employed, as Fig. 93 (*a*), Chapter 10, Part II, with 2″×1″ spruce, $\frac{1}{16}$″ plywood and depth of strut $5\frac{1}{2}$″.

TABLE 2

Loading Condition.	Front Strut.		Rear Strut.	
	Tension.	Compression.	Tension.	Compression.
C.P.F.	460×4.47	—	—	—
C.P.B.	—	—	460×3.152	—
L.N.D.	C.P.F. $\times \frac{370}{720}$	—	C.P.B. $\times 563/507$	—
Inverted	—	$460 \times \frac{4.47}{2}$	—	$460 \times .253 \times 3$

Assuming that the spruce member resists sideways failure, then $A = 2$ sq. in., and

$$I = \frac{1}{12}(2)^3 = .667 \text{ in.}^4$$

$$K = \sqrt{I/A} = 0.576 \text{ in.}$$

$$\text{and } L/K = 96/0.576 = 167.$$

By the curve for grade A spruce, Appendix VII, Fig. 195, the allowable stress is 510 lbs./sq. in.

Hence allowable load is 1,020 lbs.

Again assuming the plywood fairing resists failure in the forward direction, suppose it is considered as being of two parallel strips of depth $5\frac{1}{2}''$ and of width equal to the thickness, $\frac{1}{16}''$. Then area of plywood, $A = 2 \times .0625 \times 5.5 = 0.688$ sq. in.

$$I = \frac{.125}{12}(5.5)^3 = 1.73 \text{ in.}^4$$

$$K = \sqrt{1.73/.688} = 1.61 \text{ in. and}$$

$$L/K = 96/1.61 \quad = 59.6.$$

Now the allowable stress of good plywood is higher than that of spruce, but for safety the spruce figures may be used. Then allowable stress $= 3,000$ lbs./sq. in., and allowable load $= 0.688 \times 3,000 = 2,064$ lbs.

Calculations of this sort for plywood are very approximate only, and the results will depend largely on the soundness of

any joints in the sheeting, together with the spacing of, and attachment to, the formers, and other factors.

As, however, the streamline shape is stronger than the flat strips assumed, a low figure has been employed for allowable stress, and a higher figure than that required has been obtained, the above section should prove satisfactory.

Where there is any doubt a specimen strut should be made and tested.

Reductions in both weight and head resistance may be obtained by using a tapered strut for which the taper may take the form of a straight line or an ellipse or, alternatively, the strut may be parallel over a certain length from the centre with a taper to the ends.

The design of tapered struts is rather involved and if fuller details are required the reader is referred to the Air Ministry "Handbook of Strength Calculations," or other works on tapered struts.

The composite strut of spruce and plywood fairing cannot be easily built to an elliptical taper, and therefore sailplane struts are generally straight tapered.

The end section is first fixed by consideration of the end fittings, and is then checked for direct compressive failure. Assume a width Se of $1''$ for the strut under consideration. Next find the width that would be necessary at the centre section for a straight parallel strut. This has already been found to be $2''$. Then width at centre for a straight taper is given by $Sc^3 = \frac{S^4}{Se} = \frac{16}{1}$ and $Sc = 2.52''$.

The depth should vary to the same proportion, or since the width of $2''$ for a parallel strut was found for a depth of $1''$, the depth of the tapered strut should be $\frac{2.52}{2} \times 1 = 1.26''$ and at the ends, $\frac{1}{2} \times 1$ or $0.5''$, so that the spruce section will taper from $2.52'' \times 1.26''$ at the centre to $1'' \times \frac{1}{2}''$ at the ends.

The plywood fairing will be symmetrical and of similar shape at all sections, thus the fairing depth will be increased to about $7''$ at the centre, tapering to $3''$ at the ends.

A strut designed for compressive loads will be amply strong in tension, but the strength of the attachment of fittings should be sufficient to transmit the tension loads. This is a point of importance.

CHAPTER V

Design of Fuselage and Skids

Types of Fuselage—Fuselage Loads—Design of Fuselage Members with Worked Examples — Landing Skid — Tail Skid — Wheel Chassis.

Types of Fuselage

There are three main types of fuselage, they are :

1. Monocoque,
2. Girder type, and
3. Girder with stiff covering.

The true monocoque type is both the most efficient and the most popular for sailplanes, although it is undoubtedly the most expensive to produce. It is built up on a number of oval-shaped bulkheads, held in position by a few light longitudinal members, the whole being covered with plywood.

The girder type consists generally of four longerons held in position by horizontal and vertical struts across the top, bottom and sides, all the bays thus formed being suitably braced by diagonal struts or tension members. The covering is fabric.

Fuselages built on this principle are quick and cheap to construct and are very light, but do not give good aerodynamic shape, and are not so robust as the monocoque type, consequently they are not often used.

The third type is really a combination of the two preceding types, and is of square, or preferably hexagonal, shape in section, employing four or six longerons with struts between. There are no diagonal members, but the outside is covered with plywood, which serves also as diagonal bracing.

This provides a robust structure of fairly good streamline shape and is cheaper than the monocoque fuselage, so that it is very suitable for school sailplanes.

Fuselage Loads

The fuselage is subjected to the external loads transmitted from the tail unit in flight, from the main skid in landing, and from the starting rope during launches.

The tail plane generally has a small upward load in normal flight, and this is increased by depressing the elevators in order to dive. As the dive progresses the mainplane incidence decreases, causing the centre of pressure to move backwards, thus tending to increase the dive. To avoid this, the elevators are returned towards the neutral position, and in a steep dive are pulled above neutral so that a downward load is placed on the tail plane.

There is also a side load due to the rudder, and fin if fitted, but as the rudder loads on sailplanes are comparatively small there is generally no need to check the strength of fuselage for this condition. In the case of girder type fuselages, if the rudder is of high aspect ratio, it may be necessary to check for torsion loads in the fuselage, but this is seldom necessary with monocoque bodies.

The loadings imposed by up loads in normal flight are not of importance compared with the down loads in a steep dive, and are counteracted to some extent by the weight of the fuselage, so that they can generally be neglected.

The tail skid load is negligible, owing to the fact that the main skid makes contact with the ground almost vertically below the centre of gravity, and this case need not be considered for the fuselage.

The main landing loads fall on the principal bulkheads situated between the main spars and skid blocks and have little effect on the rest of the fuselage.

From this it is seen that the rear part of the fuselage should be designed to withstand the maximum down loads on the tail in diving and no other case need, generally, be considered.

The method of calculating the maximum tail load has been explained in Chapter I.

The remaining condition of fuselage loading is that due to launching. From tests that have been carried out it has been found that with a vigorous launch the pull on the launching hook may reach as high a value as 500 lbs. Since this is taken mainly by the front longitudinal members, in tension, and this, with a factor of 2, needs only a total cross sectional

area of about $\frac{1}{10}$ sq. in., there is little need to calculate for this providing the attachment of the hook to the longerons is properly made and sufficiently strong.

The cable loads during launching by auto-towing have been found by tests to be about 200 lbs. horizontally, changing to 200 lbs. vertically. Machines designed for launching by this method should be capable of withstanding a vertical load at the launching hook of 200 lbs. with a factor of two.

Design of Fuselage Members

This can best be explained by means of examples.

Case 1.—Girder fuselage of length 20 ft., maximum depth between longerons at main bulkheads 2′ 6″, decreasing to 1′ 0″ at tail. Divided into suitable bays as shown in Fig. 38. Tail load, 230 lbs.; pilot's weight, 150 lbs.

The most satisfactory spacing for bays has been found, by experience, to be approximately equal to the fuselage depth, although it is sometimes made as much as double this amount.

A load diagram is first drawn for the rear portion of the fuselage from which the values shown in Table 3 are obtained.

TABLE 3

Member.	Max. Load.	Nature.	Length (ins.).
Bottom longeron .	1170 lbs. (OB)	Compression	24
Top longeron . .	920 lbs. (AN)	Tension	24
Vertical member .	230 lbs.	Compression	30
Diagonal member .	300 lbs. (ON)	Tension	33

The above loads should be divided by two as only half is taken by each side of the fuselage.

Longerons.—The maximum load is on the bottom longeron and amounts to 585 lbs. on a length of 24 in.

If the longeron length is assumed to be a strut fixed at both ends, then

$$P = \frac{4 \pi^2 E I}{l^2}$$

$$\text{Hence, I required} = \frac{P\,l^2}{4\,\pi^2\,E}$$
$$= \frac{585 \times (24)^2}{4\,\pi^2 \times 1{,}500{,}000}$$
$$= 0.0057 \text{ in.}^4$$

I for a square section of $\frac{1}{2}''$ is 0.0052, and for 9/16″ is 0.0083 in.^{4}

A section of $\frac{1}{2}'' \times 9/16''$ could be used, and may taper off towards the tail. Also a smaller section could be used for the top longerons, although it is more usual to keep them of equal section, or nearly so, to the bottom longerons.

Vertical Strut.—If both ends are assumed fixed, the same formula holds good, but more usually they are assumed pin jointed at both ends, in which case

$$\text{I required} = \frac{P\,l^2}{\pi^2\,E}$$
$$= \frac{115 \times 30 \times 30}{\pi^2 \times 1{,}500{,}000}$$
$$= 0.007 \text{ in.}^4$$

A section of $9/16'' \times 9/16''$ will serve here also.

Diagonal Bracing.—If the diagonal bracing is duplicated, tension members may be used, in which case wires or other suitable cross members can be employed.

It is, however, more usual to insert diagonal struts for this purpose to take both tension and compression loads. These are calculated in a similar manner to the vertical struts: Suitable end attachments capable of taking the tension loads must be used.

The fore part of the fuselage is then dealt with in exactly the same way. (See Fig. 38.)

Main Bulkhead Struts.—It can be assumed that the total weight of the machine is taken in compression by these struts. If there are two mainplane spars, and therefore two main bulkheads, the weight may be divided between the two, but owing to the fact that in certain attitudes of landing most of the load may fall on one skid block and therefore one main bulkhead, each should be designed for at least two-thirds of the total load.

Thus, for an all-up weight of 500 lbs., each bulkhead

should be capable of taking a load of $\frac{2}{3} \times 500$ multiplied by a factor of 4, or 1,333 lbs.

If the bulkhead is similar to that shown in Fig. 39, then each vertical strut takes 1,333/2, or 666 lbs. The struts are supported against sideways failure at two intermediate points, and therefore the strut dimensions in this direction need not be so great as the thickness from front to back.

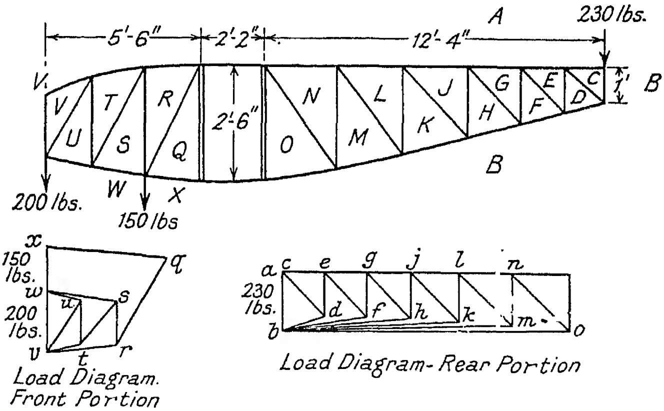


FIG. 38.—Fuselage Load Diagram.

If the total unbraced length is 30″ and a section of $1\frac{1}{4}'' \times \frac{1}{2}''$ is employed;—for collapsing load about the short axis,

$$K = \sqrt{\frac{I}{A}} = \sqrt{\frac{d^2}{12}} = \sqrt{\frac{(1.25)^2}{12}} = 0.36''$$

$$L/K = 30/0.36 = 83.4$$

The allowable stress for grade A spruce, from the curves on page 263, is 1,800 lbs./sq. in.

Hence the allowable load is $1.25 \times .5 \times 1{,}800 = 1{,}125$ lbs.

The length of strut for sideways failure is the greatest length between the supports, say 12″.

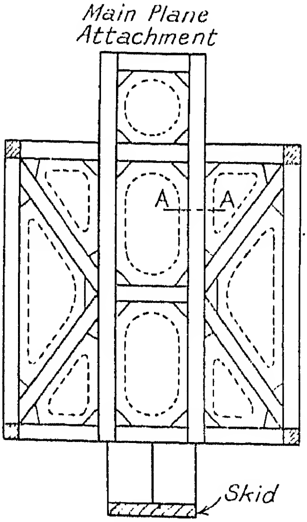
About the long axis,

$$K = \sqrt{\frac{(0.5)^2}{12}} = 0.144$$

$$L/K = 83.4,$$

the same as before, in this case, and therefore the allowable load is again 1,120 lbs.

All joints should be made with plywood gussets or, better still, if sheets of plywood are fitted on front and back, with lightening holes cut so that the plywood takes the outside shape of the bulkhead, much additional strength is given besides giving rigidity to the whole structure.



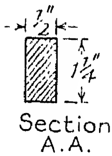


FIG. 39.—Main Frame in Fuselage.

The outline of the plywood with suitable lightening holes is shown dotted in Fig. 39.

The "neck" portion of the bulkhead should receive some consideration for its strength in bending during a side-slip.

Suppose an angle of 45° is reached and the centre of gravity is 2 ft. below the main plane.

The bending moment will equal (the total weight less that of the wing) $\times 24''$ $\times$ *sine* $45° = 300 \times 24 \times .707 = 5{,}090$ lbs. in.

This is resisted by a box spar consisting of $1\frac{1}{4}'' \times \frac{1}{2}''$ flanges and plywood webs, assuming the whole load falls on the front bulkhead. If the width apart of the flanges (vertical bulkhead struts) is 8″,

$$\text{then } I = \frac{1.25}{12}(8^3 - 7^3) = 18.65 \text{ ins.}^4$$

$$\text{and } p = \frac{5{,}090 \times 4}{18.65} = 1{,}090 \text{ lbs./sq. in, which is quite low.}$$

Case 2. Conditions as Case 1, but stiff covering to fuselage.—The alterations necessary concern the longerons, struts and diagonal bracing.

Dealing first with the bracing, the diagonal members are dispensed with altogether, the loads being taken in tension by the plywood covering.

The maximum bracing load was seen to be $300/2$, or 150 lbs. Tests on plywood panels, carried out by the author, have

shown that a plywood panel of only 1/32″ thickness will stand a diagonal load of 750 lbs. before breaking, although considerable buckling of the plywood takes place long before this figure is reached. As plywood of this thickness is seldom, if ever, used for sailplane fuselages, there is little need to check for this. To prevent distortion of the plywood, light intermediate bulkheads may be inserted.

The struts are held against sideways failure by their attachment to the plywood covering, and some reduction in thickness parallel to the fuselage axis is possible, provided that sufficient gluing area is retained.

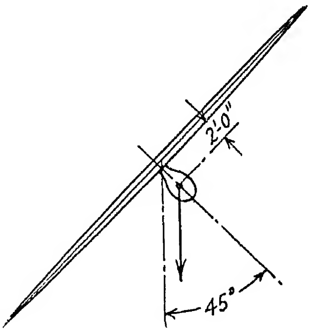


Fig. 40.
Loads during Side-slip.

For the strut considered in Case 1, for which a value of 0.007 was required for I, a section of $3/8 \times 11/16''$ has an I value of 0.01 in.^{4} about its short axis and would be suitable here.

The longerons, also, are stiffened up by the covering material and can be reduced in section to some extent. If the fuselage is of square section with plywood on two sides of each longeron they are restrained from failing in both directions, but for hexagonally shaped fuselages the longerons are stiffened up in one direction only.

It is not wise to reduce the longerons in section down to the minimum shown necessary by calculations, because adequate gluing surfaces must be provided.

Longerons of triangular section provide greater gluing surfaces than square sections of equal area, but the strut attachment is made more difficult unless the longerons are left square at each joint.

Case 3. *Monocoque fuselage, other conditions similar to Cases* 1 *and* 2.—The fuselage can be regarded as a tubular structure subjected to bending, but owing to the uncertainty of the strength of joints in plywood the longitudinal members should be capable of dealing with the tension loads.

It has already been stated, Chapter IV, page 61, that, to prevent buckling, or elastic instability, the thickness of plywood should not be less than 1/60th of the distance between supports,

but the fuselage covering gains considerable stiffness on account of the curvature of the section. Since the amount of curvature increases, and the bending moment decreases, towards the tail, thinner sheeting may be used at the back, the ideal being a general grading in thickness from the wing to the tail.

Bulkheads in monocoque bodies are usually placed about every 6 or 8 in., with every intermediate, or pair of intermediates, of quite light construction for stiffening of the shell only.

A thickness of 6/60″ or 1/10″, say 3/32″, should be sufficient for the part near the wing, decreasing to 1/25″ (1 mm.) at the end.

Assuming a bending moment figure of 230 lbs × 148″, or 34,000 lbs. ins., and a mean external diameter of 22″,

$$\text{then } I = \frac{\pi}{64}(D^4 - d^4)$$

$$= \frac{\pi}{64}\left\{22^4 - (21.8)^4\right\}$$

$$= 414 \text{ in.}^4$$

$$\text{and stress, } p = \frac{34{,}000 \times 11}{414}$$

$$= 905 \text{ lbs./sq. in.,}$$

which is quite low. The strength at other points along the length should be checked in a similar manner.

It may be noted that using the R.R.G. figure of 30 lbs./sq. ft. of surface, gives a tail load of, say, 20 × 30, or 600 lbs., in which case the above stress would be increased to 2,360 lbs./sq. in.

Checking for Torsion.—Suppose a factored rudder load of 150 lbs. with the centre of pressure 30″ above the centre line of fuselage, giving a torsion of 4,500 lbs. in.

Referring back to the design of the leading edge torsion tube for the main plane, on page 63, Chapter IV, it was seen that a 12″ diameter tube of 2 mm. thickness gave a stress of only 1,100 lbs/sq. in. for a torsion load of 20,000 lbs. in., so there is little need to check for a torsion of only 4,500 lbs. in.

It might be considered necessary to calculate for a combined torsion and bending due to tail load, say in a climbing turn, when full rudder might be used and some elevator control. A suitable value for the tail load would have to be assumed, considerably less than the full load in the terminal

dive case, and the fuselage checked for combined torsion and bending by the formulæ on page 57, Chapter IV.

Longitudinals.—The smallest section longitudinal members practicable will be sufficient to carry the tension load along the bottom and top of the fuselage.

For example, the maximum tension found in Case 1 was 920 lbs. only, and calls for a cross sectional area of $\frac{920}{9{,}000}$, or, say, 1/10th sq. in.

Two members of $\frac{1}{4}'' \times \frac{3}{8}''$ have a combined area of 0.1875 sq. in., and it would not be wise to go below this.

Alternative Method.—An alternative method for checking the strength of a monocoque fuselage is to consider it as a girder structure, in the same way as for Case 1, and to assume that the main members take one-half of the load, leaving the other half for the plywood covering. In this way the longitudinal and bulkhead members can be calculated, and this serves as a useful check for the previous method.

The main bulkheads to which the wing spars are attached are calculated in exactly the same way as for Case 1.

Landing Skid

There is little variation possible in the design of main skids, as they are nearly always made of ash with a cross section of between $\frac{1}{2}'' \times 3''$ and $\frac{5}{8}'' \times 4''$.

It is hardly possible to calculate the stresses in the skid. If the point of contact with the ground is at one of the skid supports there is no bending moment in the skid as the load is transferred directly to the bulkhead. If contact is some distance from a point of support the skid deflects and the load point tends to move towards the support.

Where the span between any two supports is large the skid deflects until it makes contact with the keel of the fuselage, and thus the bending moment is relieved.

Skid sections, as stated above, have been found to give good service and should suffice for most sailplanes.

Skid attachments should be designed to prevent sideways failure for side-wind landings.

With single spar machines the main skid shock absorbing support should be under the spar position and for two-spar

wings it is preferable to employ two supports, one under each spar.

Rigid attachment of the front of the skid is generally made at or near the launching hook, whilst the rear end is either left unsupported or is connected to the fuselage keel by a roller or sliding fitting.

Tail Skid

The tail skid is usually supported below the fuselage by a box fitting and may be either sprung or unsprung. Bamboo and leaf springs are sometimes used, but are not easily streamlined and are unpopular, besides which a built-up box tail skid makes a very suitable support point for the bottom rudder hinge.

Wheel Chassis

For auto-towing and aeroplane towing, light undercarriages are often used. These follow normal aeroplane design and can be either of the simple " Vee " or the split axle type. The point of contact of the wheels and ground should be at least 12 in. in front of the centre of gravity, with the machine in flying position.

If " doughnut " wheels are employed no other springing is necessary. The loads in the various members can be found by simple load diagrams, and a factor of four should be present.

To allow for side-wind landings, assume a factored load equal to the weight of the machine acting horizontally at the hub.

Full particulars of aero wheels, showing their shock absorbing capacity, can be obtained from the manufacturers.

For fuller details and sketches of the parts considered the reader is referred to Part II, Chapter XI.

CHAPTER VI

Design of Tail Unit and Control Surfaces

Types of Tail Units—Tail Loadings, with Worked Examples—Tail Plane and Elevator Spars—Ribs—Drag Bracing—Rudder—Ailerons.

Types of Tail Units

There are two types of sailplane tail units :

(1) The fixed tail plane with hinged elevator, and

(2) The " pendulum " type elevator.

The latter type is more often used than the former, as it has less resistance to the air, is easily detachable, is very effective in use, and allows of a neater design.

This applies equally to the rudder and vertical fin.

Tail Loadings

It was shown in Chapter I that the maximum load on the tail plane will occur either in the terminal dive or in pulling out of a steep dive, and if the tail members are designed to withstand this load there is little need to check for other loadings.

The rear spar of a fixed tail plane should be designed for an up load of 5 lbs./sq. ft. in normal flight. A C.P. position of 0.5 chord may be assumed with a rectangular loading curve.

Considering first the fixed tail plane type, the most usual shapes are shown in Fig. 41, (*a*) (*b*) and (*c*).

In type (*a*) there are generally two main spars in the tail plane, the front one being either close to the leading edge or sometimes actually taking the place of the leading edge. In (*b*) and (*c*) there is only one main spar connected at the tips by the leading edge, which sweeps back from the front attachment point.

The elevator loads are transferred to the rear main spar at the hinge positions, while the tail plane loads are found by the method given in Chapter I, page 8.

In cases (*b*) and (*c*) some assumptions may have to be made to determine the modified loading on the leading edge.

The loading diagrams used by the R.R.G. are certainly more simple to use than the British, although the unit loading is higher.

As an example, assume shape (*a*) is to be used with a tail plane of span 10 ft. and chord 1′ 3″, giving an area of 12 sq. ft., and elevator chord 1′ 3″ with an area of 10 sq. ft. Assume spar positions in the tail plane are 3″ and 1′ 3″ from the leading

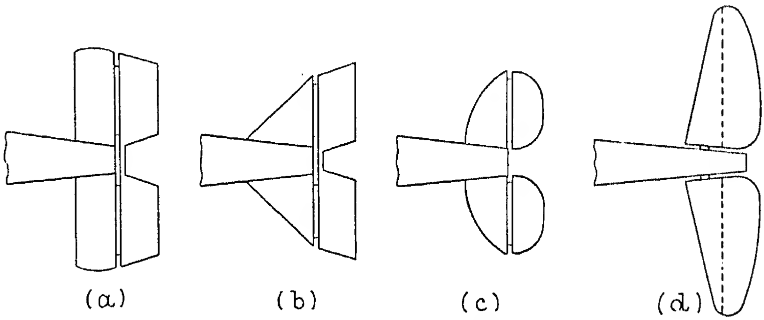


FIG. 41.—Tailplane Types.

edge and a total load of 230 lbs. in the limiting velocity dive case.

$$\text{Then } P_1 = \left\{\frac{(2-.5)^2}{(1-.5)\ (2-.5)+1}\right\} 230, \text{ from page 9.}$$

$$= 296 \text{ lbs.}$$

$$\text{and } P_2 = 296 - 230 = 66 \text{ lbs.}$$

$$\text{also } a = \frac{(1-.5)\ (2-.5)}{(1-.5)\ (2-.5)+1} = 0.428 \text{ chord or } 12.84 \text{ in.}$$

The C.P. of the down load component will therefore be $\frac{12.84}{3} = 4.28''$ from the leading edge. (See Fig. 4.)

To find the position at which the centre of pressure of the up load acts,

$$P_2 = d/_2\ (c-a)$$

$$\text{or } d = \frac{2\ P_2}{c-a} = \frac{2\times 66}{17.16} = 7.69 \text{ lbs./in.}$$

Also by dividing the up load curve into triangles to the left and to the right of the hinge position and taking moments about the trailing edge,

$$P_2 = \frac{7.69}{2} \times 2.16 + \frac{7.69}{2} \times 15 \text{ lbs.}$$

$$\text{and } P_2.x = \frac{7.69}{2} \times 2.16 \left(\frac{2.16}{3} + 15\right) + \frac{7.69}{2} \times 15 \times \frac{2 \times 15}{3},$$

where x = distance of C.P. from trailing edge,

$$\therefore P_2x = 707 \text{ lbs. in.}$$

$$\text{Whence } x = \frac{707}{66} = 10.7''.$$

The spar reactions can now be found, by reference to Fig. 4.

By moments about F—where F denotes front spar and R denotes rear spar,

$$P_2 \times 16.3 = R \times 12 + P_1 \times 1.28.$$

From which R = 58 lbs.

Also $F + P_2 = P_1 + R$,

$$\therefore F = 296 + 58 - 66 = 288 \text{ lbs.}$$

The front spar is subjected to a down loading of 288 lbs. and the rear spar to an upward load of 58 lbs.

In this case the rear spar should be designed for a tail loading of 5 lbs./sq. ft., or $5 \times 22 = 110$ lbs., from which the rear spar load can be found.

It will be noticed that if the front spar is moved closer to the leading edge the load will be lessened, but at the same time the spar depth will be diminished. If it is found possible to arrange for a suitable spar section at the leading edge, then the load will be a minimum, but it is generally more economical to place the spar further back.

Tail Plane and Elevator Spars

The front spar can now be designed for the down load found, the method being similar to that for the main plane spars.

The elevator should be considered before the tail plane rear spar, since a portion of the loads is transferred from it through the hinges.

The elevator loading may be taken as 5 lbs./sq. ft., average, but with triangular loading.

In the case of split elevators with two hinges each, at or near the ends, the B.M. curves and hinge reactions are easily found. When, however, the elevators are continuous or several hinges are used, then the three moment equation must be used, as was shown in Chapter III for the main planes.

The torsion effect must also be considered.

Torsion $= L \times C/3$ lbs. inches.

where $L =$ total load on elevator in lbs. and $C =$ chord in inches.

For a single king-post the total torsional load is present at the king-post position only, whilst on either side of the king-post the torsion is halved, or, more accurately, is proportional to the distribution of the elevator area to the left and right of the king-post. If there are more than one king-post, the torsion at each is proportional to the area covered by the king-post.

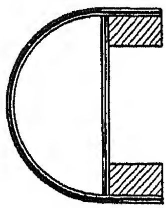


FIG. 42.
Elevator Spar, Fixed Tailplane Type.

Elevators are often built with a torsion resisting leading edge, as in the case of main planes. (See Fig. 42.)

The ply covering takes a semi-circular shape and provides a suitable leading edge for working in fairing strips behind the tail plane rear spar, so as to avoid a large gap between tail plane and elevator.

With a spar of this type the spar flanges are designed to take the bending moment only, and the torsion is taken by the ply covering.

When there is no torsional covering the spar should be of the box type and designed to withstand the combined stresses of bending and torsion, as explained on page 57, Chapter IV, for main plane spars.

There are usually gaps in the torsion covering at the hinge positions, where the torsion is greatest, and the spar should be strengthened up at these points, by inserting blocks, or other suitable stiffening.

The tail plane rear spar can then be dealt with. The bending moment curves are obtained in a manner similar to

that for the elevator with the additional elevator loads concentrated at the hinges.

In the case of the pendulum type elevator, the loads at each rib are proportional to their chord and the bending moments are quickly found.

The spar may be placed at the C.P. position which, for a symmetrical section, is situated at about one-quarter chord from the leading edge.

If the C.P. may be assumed to remain practically stationary, as with the German method of stressing, torsion need not be taken into account. But if torsion has to be allowed for, the spar or tube connecting the elevator to the fuselage must be designed for this.

Where a load curve, similar to Fig. 4 is used, the spar might conveniently be placed at the centre of pressure position of the front down load, so that the torsion is only the up load at the rear multiplied by its distance from the spar.

Ribs

The tail plane ribs are designed in a similar manner to the main plane ribs, but using the appropriate load diagrams.

Drag Bracing

The tail plane drag may be assumed to be one-quarter of the load. A suitable system of struts and bracings should be used, but where a plywood covering is employed over the tail plane leading edge this can be made to take the drag loads.

Rudder

The rudder is designed in exactly the same way as that described above for the elevators.

Ailerons

The design of ailerons is very similar to that described for the elevators. The bending moment curves are obtained with the aid of the three moment theorem. The hinges can be spaced advantageously to keep the bending moment curve along the span proportional to the spar depth.

The loading is taken as the portion over the aileron for the C.P.B. condition, or $w \times \text{area} \times \text{factor}$ for C.P.B.

The load curve is then assumed triangular, so that the maximum torsion equals, as before, $L \times \frac{C_A}{3}$,

where C_A = aileron chord.

The torsion is taken either by a stiff leading edge, or in combination with bending loads, by the spar with suitable strengthening at hinge positions.

Where there is insufficient depth of spar to resist the torsion loads over the part near the wing-tip, this can be overcome by employing a plywood covering, instead of fabric, for the outside few feet of span.

This gives rigidity to the whole, is more robust for handling, and is not so liable to damage during wing-tip landings.

CHAPTER VII

Control System and Main Fittings

Control System Loads—King-posts—Cables—Control Column, etc.—Fittings—Worked Examples of Fitting Design.

Control System Loads

The loads in the control system are calculated both by assuming certain maximum forces that may be exerted by the pilot and also by finding the actual aerodynamic loads on the control surfaces.

No attempt is made to balance one against the other, but the loads imposed in the system, due to the surface loads necessary for manœuvres, should certainly never exceed those the pilot is considered reasonably able to apply.

Heavy loads are sometimes placed on the rudder bar, or pedals, which are never necessary for control purposes, and also in the case of a jam in the system the pilot may exert considerable force to overcome the blockage.

The following conditions are laid down in the Air Ministry " Handbook of Strength Calculations " for aircraft of a tare weight up to 880 lbs., and are quite suitable as a basis for sailplane design :

A factor of 1.25 is called for in the following cases :

(1) A pull, or push on the top of control column, of 75 lbs.
(2) A tangential force on the rim of the hand wheel of 40 lbs.
(3) A side load on the top of the control column of 40 lbs.
(4) A push on one side of the rudder bar of 150 lbs., and
(5) A simultaneous push on each side of the rudder bar (or pedals) of 180 lbs.

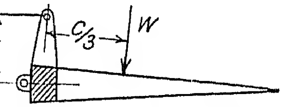
The maximum aerodynamic forces on the control surfaces have already been discussed. Assuming, in general, that the centre of pressure is one-third chord from the leading edge of the control surface and denoting the length of the king-post,

the cable attachment to the spar centre, by l, the cable

$$P = \frac{W \times C}{3\,l} \text{ where } W = \text{aerodynamic load.}$$

ome modification is necessary for balanced surfaces or abnormal feature.

he loads imposed on the rudder cables by the pilot may aken as those given above, as the cables are generally hed to the bar, or pedals, close to the pilot's feet, but for levator and ailerons the loads exerted by the pilot must be multiplied by the gear ratio of the control mechanism.



. 43.—Control Surface and Cable Loads.

If the cable loads due to the aerodynamic forces approach those as found by the table above for the pilot, the machine will prove very heavy on con- but, on the other hand, if the elevator loads are very in comparison, then the sailplane may be supersensitive even dangerous.

he best control is one that needs little exertion by the , but has a sufficiency of " feel." The friction of the over pulleys, etc., should be borne in mind when design- the system, as the pilot has to overcome this as well as ir loads.

g-Posts

he king-posts, or control levers, are subjected to a bend- noment which is a maximum at the base, where it is equal e cable load multiplied by the king-post length. Suitable gthening against sideways failure should be arranged for. or safety, the cable load should be the value as found by deration of the forces exerted by the pilot, and the main in the control surface, together with the king-post attach- to it, should be capable of withstanding these loads.

es

he control cables should allow for possible wear or fraying stretching under load, and for this reason should have a ous factor of safety. For instance, if a force of 75 lbs. sumed to be exerted by the pilot on the control column

in a backwards direction and the gear ratio of the column is five to one, then the cable load would be $5 \times 75 = 450$ lbs., or 563 lbs., say, with factor 1.25.

A 5 cwt. cable would just carry this, but it would be preferable to employ a 10 cwt. cable.

Control Column, etc.

The control column, rudder bar and lever arms are subjected to simple bending, whilst the torsion tube, if used, is subjected only to torsion. As this latter is generally a round tube the torsional resistance is easily calculated by the formula given on page 57.

The parts adjacent to the control system should be capable of withstanding all reaction loads set up by the control forces, and the strength of all pulley attachments should be checked, the load on each pulley being obtained from the maximum pull in the cable for the particular control considered.

Fittings

The types of fittings used in sailplane work are described in Part II, Chapter XII. The main function of most fittings is to connect two adjacent parts together and so to transmit the loads from one to the other.

At the present time the most favoured material of construction is timber, with steel connection fittings, so that the load is, in general, transmitted from the timber to bolts and thence to steel plates. The steel plates are joined by pins or bolts so that the load is again distributed to timber through more bolts.

There are, therefore, several different stresses set up, all of which have to be checked. In most cases the following stresses need calculating:

(*a*) Shear of timber.
(*b*) Bearing of bolts on timber.
(*c*) and (*d*) Shear of, and bearing on, bolts by fittings.
(*e*) and (*f*) Shear of, and bearing on, fittings by bolts.
(*g*) Direct stress in fittings.
(*h*) and (*j*) Shear of, and bearing on, connecting pin by fittings, and
(*k*) and (*l*) Shear of, and bearing on, fittings by pin.

Some worked examples will best illustrate the method of fitting design.

The allowable values for stresses in spruce (A) and mild steel, throughout the calculations, have been taken as follows :

Timber—	Shear stress, parallel to grain .	800 lbs./sq. in.
	Bearing stress . . .	3,000 lbs./sq. in.
Mild Steel—	Shear stress	20 tons/sq. in.
	Bearing stress . . .	38 tons/sq. in.
	Tensile stress . . .	28 tons/sq. in.

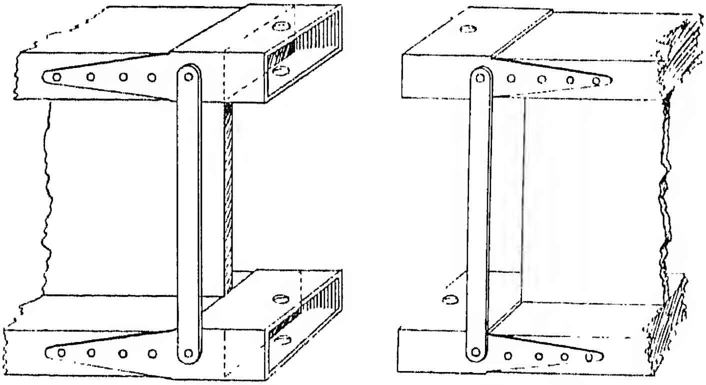


FIG. 44.—Wing Spar Fitting—" Darmstadt " Type.

Case I. *Spar Connection Fittings.*—Suppose a main plane spar connection fitting of the Darmstadt type, as Fig. 44, is 9″ deep, $2\frac{1}{4}''$ wide, with $\frac{3}{4}''$ deep flanges, and has to transmit a factored bending moment of 51,000 lbs. in., and a factored shear force of 540 lbs.

If gauge of fitting is 16 S.W.G. and attachment bolts are 2 B.A. with a connecting bolt or pin of $\frac{1}{2}''$ diameter, also if bolts are placed at the mid-flange position, then distance apart will be $9'' - \frac{3}{4}'' = 8\frac{1}{4}''$,

$$\text{and load will be } \frac{51{,}000}{8.25} = 6{,}182 \text{ lbs.}$$

(*b*) Number of 2 B.A. bolts necessary for bearing on timber

$$= \frac{6{,}180}{2.25 \times .185 \times 3{,}000}$$

$$= 4.95 \text{ or } 5 \text{ bolts.}$$

(*c*) Number of 2 B.A. bolts required for shear of bolts

$$= \frac{6{,}180}{2 \times .0269 \times 20 \times 2{,}240}$$

$$= 3 \text{ bolts.}$$

(*a*) If 5 bolts are spaced at 1″ centres, then the allowable shear of timber will be approximately $5 \times 1.85 \times 800 = 7{,}400$ lbs.

It will be noted here that the shear has been taken as acting along one face only. With bolts of larger diameter shear would have been assumed along two faces, but it is doubtful if this can be allowed for small diameter bolts.

(*d*) and (*f*) The bearing area of bolts on fittings and *vice versa* are equal, being for two plates

$$2 \times .064 \times 5 \times d = 0.1184 \text{ sq. in.}$$

and allowable load $= 0.1184 \times 38 \times 2{,}240 = 10{,}080$ lbs., taking the steel strength in bearing as 38 tons/sq. in. for both.

(*e*) The shear resistance of fittings need not be checked in this case as it is obviously of a high value.

(*h*) Allowable shear load on ½″ connecting pin

$$= \frac{\pi}{4} \times (.5)^2 \times 20 \times 2{,}240 = 8{,}800 \text{ lbs.}$$

(*j*) and (*l*) The bearing areas of pin and fitting lugs necessary

$$= \frac{6{,}180}{38 \times 2{,}240} = 0.0727 \text{ sq. in.}$$

and thickness of lugs for ½″ diameter pin

$$= \frac{.0727}{.5} = 0.1454'' \text{ or } .0727'' \text{ for each of 2 lugs.}$$

Now the 16 S.W.G. lug has a thickness of only 0.064″ and this must be thickened up by brazing on another plate or washer.

As this part is subjected to wear, both in flight and in erection and dismantling, it would be well to use a plate of, say, 1/16″ thick.

The total thickness is then 0.125″, say.

(*k*) The shear of the lug by the ½″ bolt takes place along two faces. If the radius of lug (or, in this case, the distance from the bolt centre to outer edge of lug) is $1.5 \times$ diameter of bolt, then allowable shear load for 2 lugs

$$= 2 \times 2 \times .5 \times .125 \times 20 \times 2{,}240 = 11{,}200 \text{ lbs.}$$

(*g*) Lastly the width of lug necessary, assuming the single thickness here, will be $\frac{6,180}{2 \times 28 \times 2,240 \times .064} = 0.77''$ and the width of lug at the base should be increased by the hole diameter, but in this case it is rendered unnecessary by the addition of the thickening washer.

With this type of spar joint, in which each flange is boxed with separate fittings, there is a tendency for the flanges to come apart, due to the variation of loading, and to prevent this steel tension straps connecting the two flanges are often provided. This is shown in Fig. 44.

Assuming a factored shear load of 540 lbs., it is quickly seen that a 16 S.W.G. strip of $\frac{1}{2}''$ wide steel, held to each flange fitting by an extra 2 B.A. bolt at each end, will easily carry this load.

The design of the "Professor" type of spar joint is similar to the box type, except that the joint pins go from front to back in a horizontal position instead of vertically. If the pin position is situated at the mid depth of flange, all loads and stresses are similar, but if the pins are placed closer to the centre of the spar, then the resisting moment is decreased with a consequent increase of the loads in the lugs and pins.

Case 2. Spar/Fuselage Connection Fittings.—The fittings on the main plane spar and fuselage bulkhead are generally similar (see Figs. 109 and 110), with the exception that one may be divided to form a jaw for receiving the other.

The fittings are placed in tension (or compression) for normal flight and the nose dive case, the loads to be transmitted being equal to the shear forces on the spars.

In some cases the drag, due to the wing, may be of importance. It acts at right angles to the lift loads.

For cantilever machines the forces in a bank, or side-slip, should also be considered, as well as wing-tip loads for handling, or in wing-tip landings.

For normal C.P.F. flight the load is a tension one of, say, 900 lbs. with factor. For the L.N.D. case, if a torsion value of 20,000 lbs. in., for each plane, is assumed (see page 63, Chapter IV), and the distance from leading edge to main spar is 18″, then the up load on the spar will be $\frac{20,000}{18} = 1,110$ lbs.

In a sustained bank, or side-slip, there may be a load in the fittings due to the weight of body multiplied by the horizontal offset in that position, say $W_B \times d$. If the fittings connecting fuselage to wing are d_1 in. apart, then the fitting load, $P = \dfrac{W_B d}{d_1}$

d is not likely to be more than $2 \times d_1$, which gives a value of $P = 2W_B$, without any factor. This will act in tension on one side and compression on the other.

If the body weight is taken as 300 lbs., $P = 600$ lbs. (or 1,200 lbs. with a factor 2).

Considering lastly the wing-tip load of 110 lbs. in a direction parallel to the chord and neglecting the leading edge connection to the fuselage, then if the semi-span $= 27$ ft., and fuselage fittings are 9″ apart,

$$P = \frac{110 \times 27 \times 12}{9} = 3{,}960 \text{ lbs.}$$

And this is a force which tends to shear the connecting pins.

Using 2 B.A. bolts, $\frac{3}{8}$″ connecting pins, and a bulkhead thickness of 1″, the number of bolts required for the tension case is:

(*b*) by bearing on timber $\dfrac{1{,}200}{1 \times .185 \times 3{,}000} = 2.16$

(*c*) by shear of bolts $\dfrac{1{,}200}{2 \times .0347 \times 20 \times 2{,}240} = \cdot 385$

Hence three 2 B.A. bolts should be used.

(*a*) Shear of timber, allowable load for 1″ spacing of bolts
$= 3 \times 1 \times 800 = 2{,}400$ lbs.

(*d*) and (*f*) Allowable bolt and fitting bearing stress
$= 2 \times .064 \times 3 \times d \times 38 \times 2{,}240 = 5{,}890$ lbs.

(*h*) Shear load on pin. Here the load of 3,960 lbs. due to the wing-tip landing case is used.

$$\text{Allowable load} = \frac{2 \times \pi \times (.375)^2 \times 20 \times 2{,}240}{4} = 9{,}900 \text{ lbs.}$$

(*j*) and (*l*). The bearing load for pins and lugs need not be checked here as the areas are large.

Owing to the greater thickness of the spar a smaller number of bolts may be employed, but for the sake of general robustness it would be a doubtful economy, in fact for cantilever wings the loads in cross-wind landings, handling, etc., are likely to be greater than those designed for, so that it is usual to make these connecting fittings of considerably greater strength than is shown necessary by calculations.

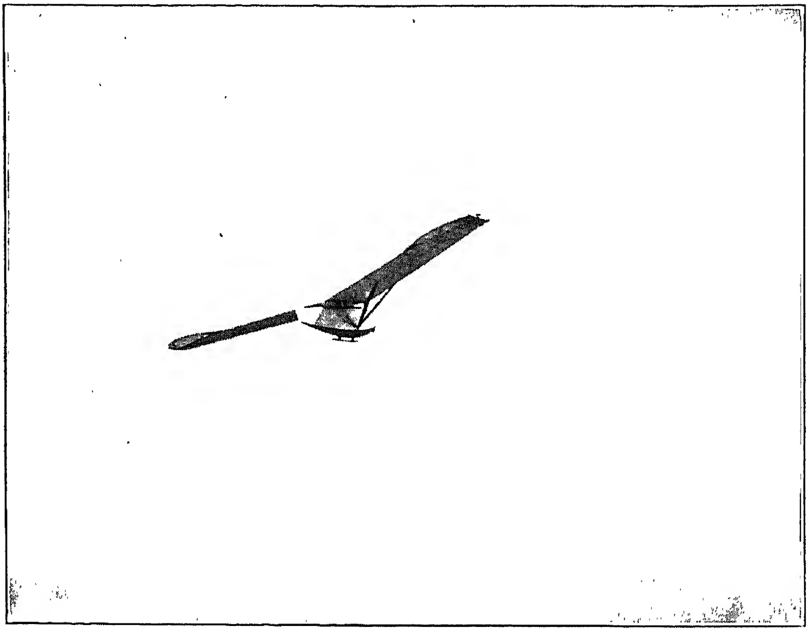


FIG. 45.—The "Stork" in Sailing Flight.

[*To face page* 95.

CHAPTER VIII

Unusual Designs and Auxiliary Devices

Tailless Sailplanes—Ornithopters—Air Brakes—Slotted Wings—Multi-Slots—The Possibilities of Sailplane Wings of Bird Form—Soaring Birds.

Tailless Sailplanes

Tailless design would appear to be especially suitable for sailplane purposes on account of the inherent low resistance and weight and, indeed, from the experience so far gained there seems a very promising future for this type of machine.

Until recently it had been considered essential to give considerable sweepback to the main planes in order to place the elevators, or their equivalent controls, at some distance behind the centre of gravity of the machine so that sufficient leverage could be obtained for manœuvring purposes. In other words the actual "tail volume," or tail area multiplied by the lever arm, was made to compare as favourably as practicable with the usual control figures for normal machines.

Lately, however, machines have been built with sweepback to the leading edge only, and even with no sweepback at all. In such cases both the aileron and elevators are situated along the trailing edge and the movement of the elevators is exactly opposite to that of the elevators placed at the tips of swept-back wings.

The reason for this is as follows: In normal aeroplanes and swept-back tailless aircraft a decrease in the incidence of the tail or elevators causes the tail to fall, thus placing the machine in a climbing attitude, and in consequence the machine tends to rise, whereas with a tailless machine, having no sweepback, a climb is obtained by increasing the lift of the main planes, and this is done by depressing the elevator, which in effect increases the incidence.

The latter method is a positive action only, giving extra lift, and is accompanied by no downward force such as is

inevitable with normal types where extra lift is gained at the expense of a negative or reduced lift on the tail.

A necessary characteristic of the tailless aeroplane is a small range of movement of the centre of pressure over the normal flying angles obtained by a wash-out of the wing towards the tips, or else by employing a wing section having a constant centre of pressure position. This is a decided disadvantage, as wash-out is accompanied by a loss of efficiency, and known aerofoils with fixed centres of pressure, often symmetrical in section, have low maximum values of lift coefficient. Some wash-out towards the tips is sometimes incorporated so that the wing near the ailerons remains unstalled after the central portion stalls.

In the orthodox type of aeroplane the upsetting moment due to the change of centre of pressure position is compensated for by the tail plane and elevator, the latter being sometimes called the stabiliser for this reason. Owing to the considerable leverage of the tail, only small angular movements of the elevator are necessary to counteract this upsetting force for all normal manœuvres, and a reasonable reserve of power is available for emergencies or more violent manœuvres.

The lever arm cannot very well be made as long on swept-back tailless machines, and with tailless craft having no sweep-back at all the elevators have no leverage about the lateral axis, and therefore a stationary centre of pressure is essential for stability purposes.

The tailless design suffers from one other disadvantage, although this is compensated for, to a certain extent, by extra beneficial qualities which are generally gained as a result. This refers to the rudder position, which has to be on or near the wing-tip in order to obtain sufficient turning leverage, and as turning is obtained by exerting a drag on one side, it becomes essential to have two rudders, one on each tip. These cannot be used together for a turn or their effects would be neutralising, and a turn to one side is therefore made by moving the rudder outwards on the side to which the turn is desired.

Thus it will be seen that the parasitic drag of two rudders cannot be avoided, although only one can be used at a time for turning.

This arrangement, however, has two distinct advantages.

In the first place both rudders may be used together to form an efficient air brake so as to increase the gliding angle and so facilitate landing in a confined space, and, secondly, when the rudders are placed at the extreme wing-tips they act also as a check to the air flowing from the underside of the wing to the above and, in this way, end losses are very much reduced.

Attempts have been made to overcome the resistance of the rudders, when not being used, by employing split ailerons so that they can be made to open like a jaw and thus place a drag on that wing or, alternatively, the wing-tip itself may be split in this way so that when not in use as a rudder it supplies

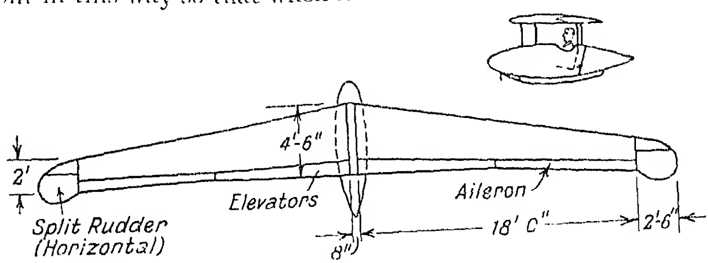


FIG. 46.– Dr. Kupper's Tailless Sailplane.

a useful lift and does not therefore constitute a parasitic drag member.

A sailplane on these lines has been produced in Germany by Dr. Kupper, and is shown in the illustration. The wings are cantilever, have slight sweepback, and slight taper with an area of about 130 sq. ft., and an aspect ratio of 13, and are supported on a small centre section built rigidly to the nacelle.

Owing to the simplicity of construction the weight is very low, being only 110 lbs., and the machine is certainly a valuable contribution towards the solution of true soaring flight.

An interesting feature of this machine is the inverted control column, which is suspended from the top of the cockpit where there is a universal joint, and a system of pulleys to give the necessary aileron and elevator controls.

Although this method simplifies the control system, in that the cables pass straight out and into the wings, it is not to be recommended owing to the peculiar movements of the control stick. For example, it may be fairly natural to pull the stick backwards and upwards to climb, but pushing forwards

and upwards to execute a dive does not appeal and seems wrong.

Other tailless machines built in Germany, to the designs of Lippisch, have included the "Storch" and the "Schwanzlose." The former had slightly tapering wings and a certain amount of sweep-back and dihedral. Rudders were situated on top of the wing-tips and only one pair of control surfaces was fitted to the trailing edges to take the place of both ailerons and elevators. This machine was later fitted with an 8 horse-power engine and attracted much attention by its high top speed.

The "Schwanzlose" is a two-seater, which has also flown as a power machine and, in the same way as the "Storch," was first produced and tested as a model, to about one-sixth full scale, giving a span of about 8 ft., and after certain modifications, that appeared desirable, had been made, it was reproduced full scale and flown as a glider. The engine was fitted after successful flights as a sailplane.

The span is about 45 ft. with chord decreasing from 9 ft. at the centre to 2 ft. 3 in. at the tips, giving an area of about 250 sq. ft. and an aspect ratio of 8. It is claimed that the low resistance resulting from the simple structure without a tail unit, together with the reduced end effect losses, give the machine a performance equivalent to that of a normal machine with an aspect ratio of 20 and a gliding angle of 1 in 20.

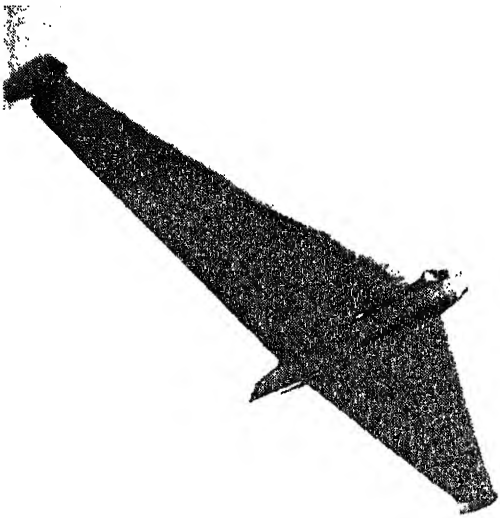
The "Schwanzlose" is a cabin machine, and as the wing is about 2 ft. deep at the centre, where it forms the top of the cabin, the actual nacelle is quite small. Dihedral is obtained by making the top wing surface flat so that the lower surface slopes up towards the tips.

Sweepback is given to the leading edge only, the trailing edge being perpendicular to the longitudinal axis in plan.

These designs are especially interesting and provide an important example of the value of gliding as a link between the drawing office and the efficient aeroplane.

Ornithopters or Flapping Wing Machines

The project of flight in which propulsion is obtained by means of the up and down movements of wings, closely resembling that of birds, has received a certain amount of attention ever since the earliest attempts at mechanical flight.



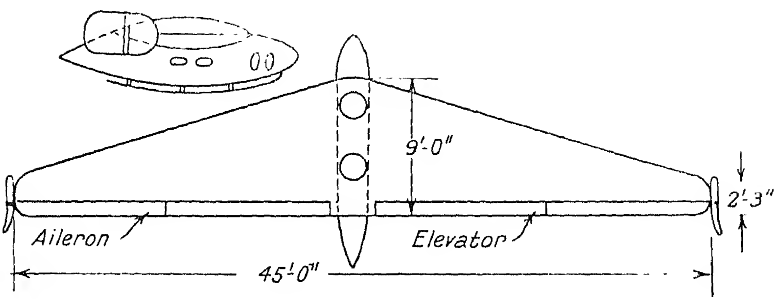


FIG. 47.—The Lippisch Two-seater Tailless Sailplane.

[To face page 98.

Many years ago a flapping machine, or ornithopter, was built to be driven by means of a powerful steam engine. Each wing was supported at approximately its central position by a rod connected to a piston working in a large cylinder. The machine never left the ground owing to the tremendous power required to move a wing up and down in this way, and experiments of such a nature were dropped for a long time.

Of recent years, however, the subject has received a revival of interest. Captain Dibovsky, a Russian airman, after watching, both from the ground and from the air, the flight of eagles in the Caucasus mountains, commenced to construct models based on a new principle. In the same way as control surfaces of aircraft are balanced by placing the hinge position back from the leading edge, or closer to the centre of pressure

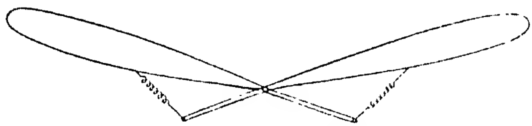


FIG. 48.—Dibovsky's Ornithopter.

of the surface, in order to lighten the load to be expended by the pilot, Dibovsky thought of balancing the wings so that only a small force would be required to actuate them. This was successfully demonstrated with a number of models he built, although he has not yet succeeded in adapting the principle to human flight.

The apparatus consisted essentially of a pair of wings hinged at the centre so that up and down, together with a certain amount of fore and aft, movements were available. The main spar of each wing extended below the other plane for a distance of about one-third of the semi-span and a piece of elastic material, or a spring, connected from the end to the centre of pressure point of the other plane. The tension of the spring was adjustable.

When in flight the weight of the pilot, etc., causes the body of the machine to sink, but the resistance of the wings by retarding the downward motion tend to close them up to some extent, causing extensions of the springs. A force is now exerted to bring the wings down again into a horizontal position, which is assisted to a considerable extent by the return action of the

springs, and in this way the flapping motion can be continue by the exertion of very little effort.

Dibovsky maintained that such a machine could l flown for long distances by means of man's own power, whic could be transmitted through pedals. One disadvantage (the method is the difficulty of obtaining an efficient design (account of the projecting spars.

Another design, based on a similar principle, employs ; before, wings hinged at the centre, together with a large le pattern spring mounted above the wings and held down ; the wing privoting point. (See diagrammatical sketch, Fig. 4(

The manner of working is the same as previously explaine and this method also suffers through the air resistance caus by the drag of the spring.

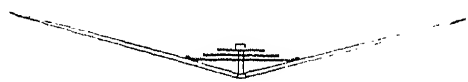


FIG. 49.—Flapping Wing Device.

Still another method of obtaining a solution to the probl of pulsating flight has been devised by Batten,[1] in which t wings are again pivoted at or near the middle, and which ; restrained from upward movement by some equivalent a bird's muscle. In his experiments (see Fig. 50), artific muscles, or torses, were formed by skeins of natural silk, wound round a rod, B, with a lever, C, rigidly attached right angles to B. A heavy weight, D, was fixed on to lever arm, which latter was set into a horizontal position tightening the twist of the torses. The weighted lever is into oscillation by gentle twisting of the bar, B, with operator's finger-tips, so that a weight of 60 lbs., situated 5 out, could be oscillated 100 times through a height of 5 without fatigue on the part of the operator. In this w a regular series of beats is obtained.

The silk used for this arrangement consisted of 10 skei weighing only 2 lbs., and after 5 years' service the silk was s unfrayed and had lost nothing in strength or resilience.

Such an apparatus, in modified form and acting in reverse direction, of course, has obvious possibilities

[1] See *An Approach to Winged Flight*, by J. D. Batten, published in 1(

ornithopter flight. For instance, by adapting the arrangement shown, without any main alteration and assuming the period of beat is suitable, the torse weight for each wing would be somewhere in the neighbourhood of 20 lbs.

In Germany the problem has received a certain amount of attention and some practical results achieved with a measure of success.

Dr. Brustmann built a flapping machine with which short flights were made during 1925. Encouraged by these results, and incorporating the lessons learnt with the first machine, a second one, a sailplane of some 33 ft. span with a wing area

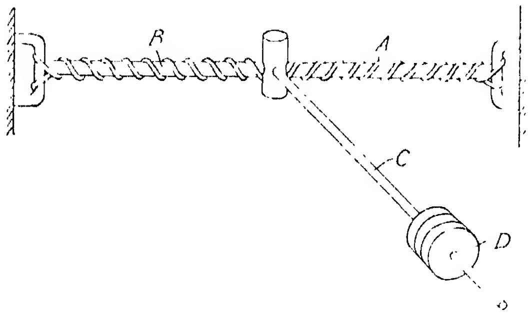


FIG. 50. Batten's Experiments for Flapping Flight.

of 130 sq. ft. was produced by 1928. Although complete success has not yet been attained, this may be claimed as the first ornithopter sailplane capable of flight.

The machine is not unlike a normal intermediate type sailplane, having tapering wings and the usual tail unit, but the main planes are hinged at the centre to allow up and down movement and are braced by a pair of struts, one to each plane. These struts attach just behind and below the pilot. No lateral control was provided, but side movement of the control column actuated the rudder.

The sailplane was first tested out on the level as a normal glider, and had a similar performance, after which flapping flights were carried out, which increased the speed and about doubled the distance possible with fixed wings.

The machine is still being tested out at the Wasserkuppe, from which useful data on this type of flight is being acquired.

springs, and in this way the flapping motion can be continued by the exertion of very little effort.

Dibovsky maintained that such a machine could be flown for long distances by means of man's own power, which could be transmitted through pedals. One disadvantage of the method is the difficulty of obtaining an efficient design on account of the projecting spars.

Another design, based on a similar principle, employs as before, wings hinged at the centre, together with a large leaf pattern spring mounted above the wings and held down at the wing privoting point. (See diagrammatical sketch, Fig. 49.)

The manner of working is the same as previously explained, and this method also suffers through the air resistance caused by the drag of the spring.

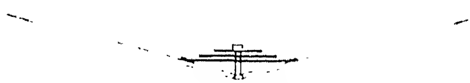


FIG. 49.—Flapping Wing Device.

Still another method of obtaining a solution to the problem of pulsating flight has been devised by Batten,[1] in which the wings are again pivoted at or near the middle, and which are restrained from upward movement by some equivalent of a bird's muscle. In his experiments (see Fig. 50), artificial muscles, or torses, were formed by skeins of natural silk, A, wound round a rod, B, with a lever, C, rigidly attached at right angles to B. A heavy weight, D, was fixed on to the lever arm, which latter was set into a horizontal position by tightening the twist of the torses. The weighted lever is set into oscillation by gentle twisting of the bar, B, with the operator's finger-tips, so that a weight of 60 lbs., situated 5 ft. out, could be oscillated 100 times through a height of 5 ft. without fatigue on the part of the operator. In this way a regular series of beats is obtained.

The silk used for this arrangement consisted of 10 skeins, weighing only 2 lbs., and after 5 years' service the silk was still unfrayed and had lost nothing in strength or resilience.

Such an apparatus, in modified form and acting in the reverse direction, of course, has obvious possibilities for

[1] See *An Approach to Winged Flight*, by J. D. Batten, published in 1928.

ornithopter flight. For instance, by adapting the arrangement shown, without any main alteration and assuming the period of beat is suitable, the torse weight for each wing would be somewhere in the neighbourhood of 20 lbs.

In Germany the problem has received a certain amount of attention and some practical results achieved with a measure of success.

Dr. Brustmann built a flapping machine with which short flights were made during 1925. Encouraged by these results, and incorporating the lessons learnt with the first machine, a second one, a sailplane of some 33 ft. span with a wing area

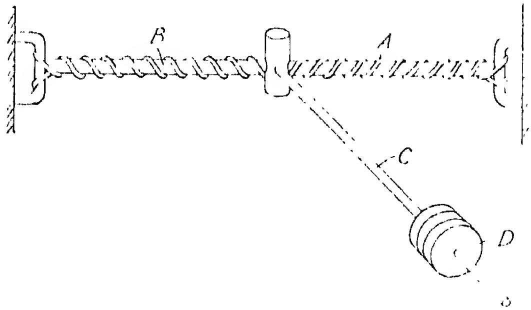


FIG. 50. Batten's Experiments for Flapping Flight.

of 130 sq. ft. was produced by 1928. Although complete success has not yet been attained, this may be claimed as the first ornithopter sailplane capable of flight.

The machine is not unlike a normal intermediate type sailplane, having tapering wings and the usual tail unit, but the main planes are hinged at the centre to allow up and down movement and are braced by a pair of struts, one to each plane. These struts attach just behind and below the pilot. No lateral control was provided, but side movement of the control column actuated the rudder.

The sailplane was first tested out on the level as a normal glider, and had a similar performance, after which flapping flights were carried out, which increased the speed and about doubled the distance possible with fixed wings.

The machine is still being tested out at the Wasserkuppe, from which useful data on this type of flight is being acquired.

That the value of pulsating wings as a source of energy for gliding is receiving wider attention is shown by the fact that some notes dealing with the subject have recently been published by Prandtl.

Air Brakes

There are a few instances of air brakes being supplied to sailplanes, and these have taken three forms.

The first type is the rudder brake, which can only be used when twin rudders are fitted, and which is brought into operation by the actuation of both rudders at the same time and in opposite directions.

The second method employs a spoiler arranged along the leading edge which can be opened at the pilot's will so that the air flow over that part of the main plane is spoilt, causing a loss of lift and extra drag and hence a coarser gliding angle.

A third form is obtained by splitting the rudder or aileron control surfaces in such a way that they may be opened in the manner of jaws and thus cause a drag.

Still another way of obtaining braking, sometimes used with power aircraft, but which has not yet been incorporated on sailplanes, consists of so arranging a pair of struts that they may be rotated through a right angle, thus presenting their larger surface towards the air flow.

Considerable difficulty is often experienced in bringing a sailplane in to land over a region subjected to up-currents, and if the stretch of ground is restricted in size the descent may be somewhat hazardous. The effect is similar to landing a normal aeroplane with engine partly on.

This is where the air brakes are of such assistance, and it is certain that the number of damaged machines could be materially reduced by the universal fitting of suitable braking devices.

The use of twin rudders for brakes is quite sound as, even when operated as brakes, their normal functioning powers are still available. A turn can be made whilst braking by releasing the rudder on the side opposite to that in which the turn is required.

Wing spoilers are very effective, but care should be exercised to place them so that the air flow over the ailerons and elevators

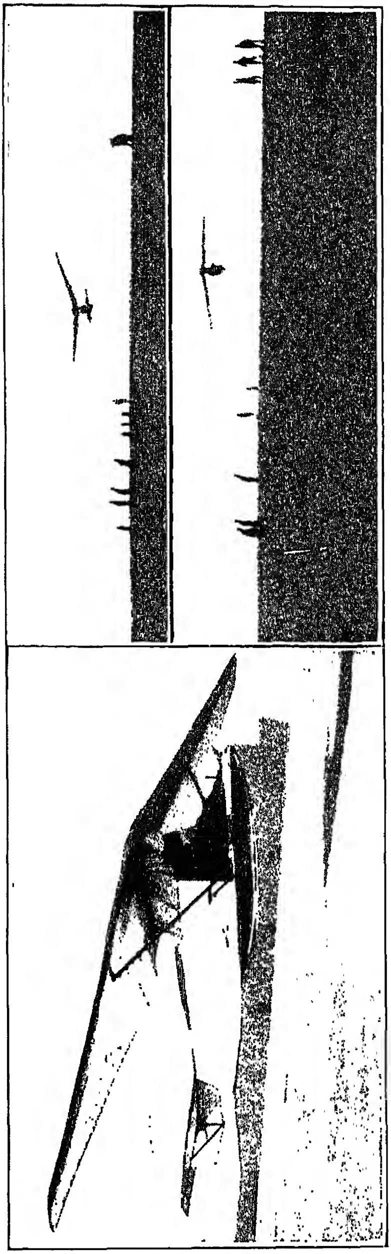


FIG. 51.—An Ornithopter Sailplane to the Designs of Dr. Brustmann.

[*To face page* 102.

is not affected, and for this reason the best position is half-way along the span between the fuselage and wing-tips.

Air brakes constitute a valuable asset, but their action is really negative, and it would be much preferable to fit a positive action device such as the well-known slotted wing.

This would allow slow landings to be made with safety, apart from which it has many other advantages, as outlined below, and recommends itself as being far superior to brakes and spoilers.

Slotted Wings

Up to the present no case has been known of sailplanes having been fitted with wing slots, although it would appear that such a step would constitute a very valuable development.

The advantages of slots may be stated as an increased lift with higher stalling angle, combined with the retention of lateral control beyond the normal stalling point, all of which are very desirable qualities for a sailplane.

The greatest use of slots up to the present has been for the improvement of lateral control, for which purpose the auxiliary aerofoils are fitted along the leading edges in front of the ailerons. When the main plane stalls, or more accurately just before stalling point, the slots open and the air flow over those parts of the wing behind the slots continues to act in a normal way, without serious burbling, so that not only is the lift retained, but also good aileron control is still available. In this way spinning, the inevitable product of a bad stall, is prevented and even voluntary spinning is made difficult.

When there is little wind and soaring is difficult the sailplane pilot is tempted to hold up the nose of the machine in an endeavour to retain his height, with the result, quite often, that he stalls and spins. Actually the resulting spin is flat and fairly slow, so that even if there is not sufficient height to right the machine and for flying speed to be regained, the resultant crash is seldom serious for the pilot, although, of course, the sailplane is generally badly damaged.

From this it will be seen that partial slotting of sailplanes appears desirable. Furthermore good lift qualities are so essential a feature of engineless aeroplanes that the increase due to slots along the whole leading edge would seem a decided advantage, especially on such occasions when the wind velocity

is rather low. When a gust of wind reaches the machine it is usual for the pilot to pull back the control stick slightly to obtain the maximum height from the gust, but if he fails to notice when the gust dies down he is left holding the machine in a stalled attitude and the result is generally a loss of height. If, however, slots were fitted the stall would be avoided by their opening, and this would give the pilot sufficient warning to ease the stick forward.

The best arrangement would appear to be one in which the main slots open first with a delayed motion of the aileron slots, since this would best ensure safety, and this could be accomplished either by arranging the setting of the slot pivots for the desired effect or by a wash-out of the wings at the tips as explained earlier in the chapter, in connection with tailless aircraft.

Multi-Slots

Some experiments have been carried out in connection with multi-slots, and these have shown that a large increase in lift can be obtained by this method. There is not the slightest doubt that such an arrangement would be of enormous benefit in sailplane design.

The increased drag would not be serious, providing a good figure could be obtained for L/D, and the slower speed gained through the high lift values would enable the machine to stay in the region of the best up-currents without the usual loss of height occasioned through passing beyond the most effective region, and again due to the banked turn executed in an attempt to regain the rising air currents. In other words, the pilot would be able to hover over one spot, without apparent movement, until maximum height had been obtained, whilst any slight lateral instability would be checked by the automatic aileron slots combined with the natural stability of the machine.

Having gained the greatest height from any one region of rising air the pilot would depress the nose of the sailplane and thus close the slots so as to transform the machine into a clean, efficient glider, capable of high speed by virtue of the small main plane area in the closed condition. This would enable a fast glide, down wind for preference, at the optimum angle of descent to the next hill or other source of lift where he would once

again face into the wind, open the slots, and repeat the process of gaining height.

This, in effect, is exactly the procedure of birds, and it is most significant that all soaring birds are supplied with well defined slots.

There may be certain structural difficulties to be overcome before such a machine can be produced, but these should be by no means insuperable, and there seems little doubt that the principle will be adopted before long in sailplane design.

The landing and take-off qualities would also be very materially improved and landings would be made even safer than at present, owing to the low speed.

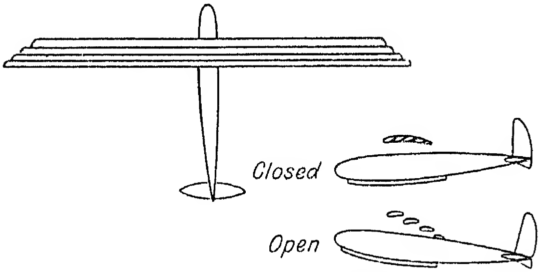


FIG. 52.—Multi-slot Sailplane.

Still another advantage to be derived from the multi-slots rests in the smaller wing surface area that would be required and the consequent smaller span. The ultra-large spans of existing sailplanes are undesirable both for flying and housing purposes whilst the present line of development is producing still larger spans.

Ailerons should prove unnecessary with multi-slots, as a turn would be made by increasing the lift of one wing through the opening of slots or, alternatively, if the slots were already open a decrease of lift would be caused on the opposite side by closing the slots on that side.

Such a scheme as has been outlined would lead the way for a similar design to be introduced for powered flight and would once again prove the usefulness of sailplanes as a means of research.

The possibility of a tailless multi-slot sailplane, combining the advantages of slots with those of tailless craft, should not

be overlooked. In this case elevators also would be rendered superfluous, height being gained or lost by opening and closing the slots. The only essential control would be a rudder, or rudders, and even this might be eliminated by arranging for the extreme auxiliary aerofoils on each wing-tip to act as spoilers.

The Possibilities of Sailplane Wings of Bird Form

Hitherto it has been considered impracticable to imitate more closely the bird's wing structure in aeroplane design, although some of the earliest attempts of flight were made along these lines. The progress of aviation seems to have come nearly to a standstill as far as the general principle is concerned, and present-day improvements are mainly concerned with engines and better streamlining of structures, so that it may well be that the working out of some new principle will be necessary before aviation becomes a complete commercial success.

The disadvantages of the present design are the large spans and wing areas of machines built for passenger carrying or freight purposes, and even these are only capable of lifting a few tons, at most, of useful load, whilst it cannot be claimed that aeroplanes are completely safe for general use on account of their fast landing speed, length of run on landing, and their liability to stall to earth after losing flying speed.

The great majority of accidents are due to stalling near the ground or through the lack of a suitable landing space after engine failure.

How far can these defects be obviated by a closer imitation of nature ?

Before considering the bird's wing it is well to bear in mind that it has to fulfil at least two other purposes besides that of sustentation in flight, and it is somewhat difficult to analyze the shape and distribution of a wing according to the demands of the different qualities.

These two requirements are firstly the means of propulsion and secondly folding. For the former the wings must be capable of flapping and be efficient as a propulsive mechanism, whilst the latter quality requires that the wing when folded should fit tightly and neatly round the body both for compactness and warmth.

The Formation of a Bird's Wing.—The feathers of a wing may be divided into four parts: (*a*) *The primary feathers* form the outer half of the wing and can be spread out to form individual aerofoils for slow speed and climbing purposes. In

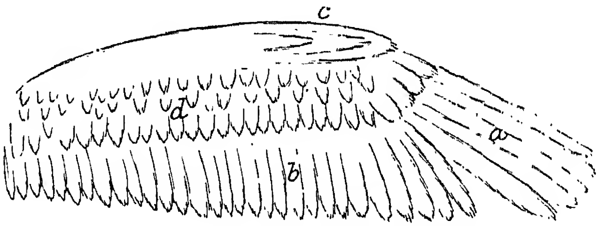


FIG. 53.—Formation of Bird's Wing.

this condition they extend as nearly perpendicularly to the body axis as the joint to the wing member will allow and thus form an efficient multi-slot device. The shape of these feathers is shown in Fig. 54, where it will be noticed that the gap, or slot, between the feathers is very definite in its formation, although this is not so pronounced in all cases. The length of the slot extends along the outer third of each wing and in some cases is even greater.

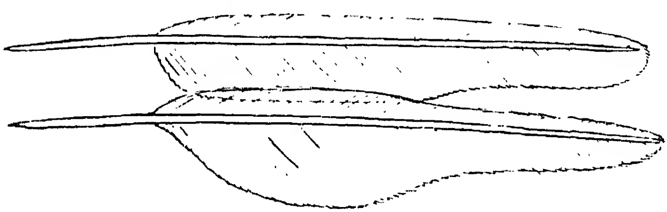


FIG. 54.—Shape of Primary Feathers.

When the primary feathers are in the open position the lift is very considerably increased, causing the shafts to flex upwards towards the tips, and as this is more pronounced on the front quills the resulting arrangement is similar to that shown in Fig. 55.

Another point of interest is that the supporting shaft is closer to the front than the back so as to be near the position of the centre of pressure and so avoid any undue twisting of the feather. It will also be noticed that the leading edge of one feather

goes over the trailing edge of the one in front, whereas in multi-slot experiments the opposite has been the case. If, however, small aerofoils could be made of quite thin sections it might be advantageous to copy the bird in this respect. The primary feathers are used for propulsion and are sometimes referred to as "rowing" feathers.

(b) *Secondary Feathers.*—The secondary feathers constitute the larger part of the wing and extend from the main member almost straight backwards to form a flexible trailing edge. This is of importance, as local uneveness in the air structure deflects the trailing edge and does not affect the stability of the bird as a whole. This part forms with the wing member the main lifting surface.

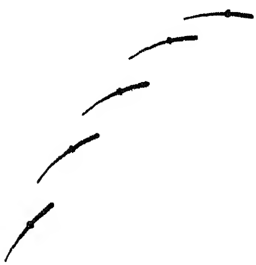


FIG. 55.
Primary Feathers in Open Position.

(c) *The alula or "false wing"* feathers which extend outwards along the leading edge are generally situated at about the mid-span of the wing, or slightly inwards, and occupy about one-quarter of the length of the leading edge. These feathers constitute an exact equivalent of the slotted wing of aeroplane practice and are used in the same manner.

(d) These small *covert* feathers give the finish to a wing. They are fairly numerous, act as a fairing to the actual limb, complete the aerofoil section of the main part of the wing, and are necessary, no doubt, for warmth.

From all that has been said it is seen that a bird can use its wings for sustentation over a large range of speeds. It does not seem quite clear why the alula feathers do not extend over the inner portion of the wing, but it will be noticed that with most birds there is a reduction in chord towards the centre, so that the chief portion is slotted, whilst the outer part has the multi-slot arrangement of the primary feathers. It may possibly be that the inner portion cannot be twisted through a large angle and is in consequence never stalled.

It might be asked why the whole wing is not on the multi-slot principle, and it appears very probable that this would have been the case but for the requirements of folding and propulsion and the almost impossible arrangement that would be required for the muscular system.

A further point of interest in connection with birds' wings is that the amount of camber decreases towards the tips, which suggests that the inner portions are designed for high lift and therefore constitute the main supporting surface, whilst the tips are shaped with small camber for high speed and are suitable for propulsion.

Considering the several functions of a bird's wing, the natural arrangement is undoubtedly a very efficient design.

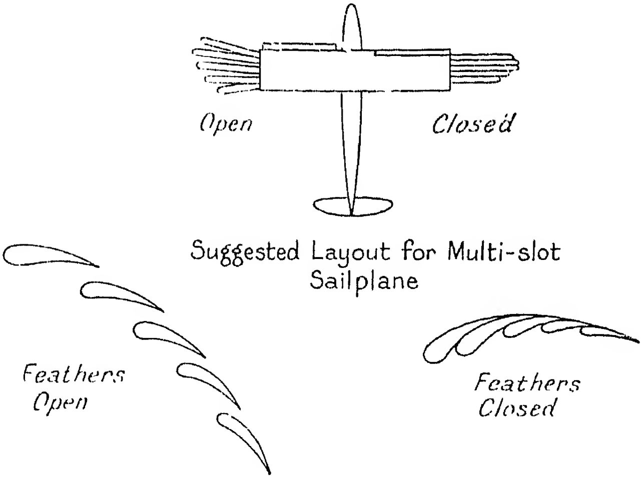


FIG. 56.

The problem then is to extract only those features necessary for sustentation and to expand the use of these without being tied down by the enforced limitations as obviously exist in the case of birds' wings.

The ideal aeroplane wing would appear to consist of aerofoils of small chord and high aspect ratio capable of acting independently, when opened out for slow flight, and forming one aerofoil for high speed in the closed condition. Up till now this has been regarded as impossible of attainment on account of the structural difficulties, but these could be overcome, and it may be that the sailplane will be the means of showing the way.

Eventually it may be that the whole main plane will consist of multi-aerofoils, or feathers, capable of being opened or closed

at the pilot's will, or automatically, depending on the flight attitude and the speed of the aircraft, but before reaching that stage a natural stepping-stone would be a closer imitation of the bird's wing as regards the plan lay-out.

The slotted wing is now perfected, corresponding to the false wing or alula, and the next stage is the adoption of the primary feathers. Fig. 56 shows a suggested lay-out for a sailplane incorporating the wing slot and wing-tip "feathers," together with sections through the wing in both the open and closed conditions; these being equivalent to slow speed, or soaring, and high speed respectively.

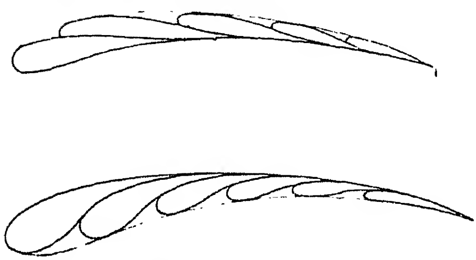


FIG. 57.—Multi-aerofoil Wing Section.

Whether the most efficient arrangement is with the leading edge of each "feather" over or under the trailing edge of the one in front is not known at present, but this could soon be decided by wind tunnel experiments. A cleaner outline to the whole is obtainable with the latter arrangement (see Fig. 57), but, with the former, the incidence of each successive small aerofoil increases towards the rear, and they are thus well positioned, for high lift, immediately opening takes place.

As regards shape, the "feathers" should be so arranged that each has a high lift wing section for the open condition and should form, as far as practicable, a high speed aerofoil section when closed.

The construction could be quite simple, consisting of a main tube, or spar, situated at one-third chord from the front, with a stiff covering of plywood, light metal, or other suitable material. The weight of such an arrangement need not be excessive.

Soaring Birds

Careful examination of the shapes and lay-out of the wings of soaring birds is recommended, besides which much can be learnt from their methods of soaring. The following is a list

of the chief soaring species: albatross, eagle, gull, vulture, kite, falcon, conder, hawk, kestrel and the common crow. In England the most common examples are, of course, the gull and crow, whilst hawks are also fairly numerous, but keep to the more uninhabited parts, and are generally found in hilly districts.

The gull is a beautiful and inspiring sailing bird, but being a sea bird is not seen much inland. There are nearly always a few gulls following a steamship, and they may be seen gliding gracefully along for mile after mile with scarcely any flapping of wings, except an occasional movement for stability purposes. The heat from the ship's funnels causes an upward flow of the surrounding air, thus making continuous soaring an easy matter. These flights often continue all through the day and night, so that the birds may cover thousands of miles in a few days with very little effort on their part.

Long sailing flights in the cliff up currents may be witnessed when the wind is blowing in from the sea. By this means the sea-gulls travel many miles up and down our coasts.

The common crow abounds almost everywhere in this country. It appears rather cumbersome and slow, and retains the primary feathers in the extended condition most of the time, both for soaring and flapping flight. Crows may be seen soaring, often in numbers, along a belt of trees, a cliff, or hillside, and where these face into the prevailing wind they become regular haunts with the nesting-place conveniently near. Their flight is well worthy of watching, as it forms a good example of flight with multi-aerofoils.

Hawks may be seen soaring over hillsides, preferably of a wild nature. They hover without perceptible movement in any direction, as though fixed in the air. After several seconds, or even minutes, a quick turn is made, followed by a swoop downwards and to one side, climbing again on the rising air with the increased speed resulting from the dive, and with a final and sudden turn into wind again, where it remains stationary once more.

Careful observation will often reveal a continuous flutter of the outspread tail, and it is undoubtedly this that enables a fixed position to be retained, whilst small movements of the wing-tips are also made for retaining lateral balance.

The hawk soars with the head and tail well depressed,

and appears to be very close to the stalling point the whole time.

The albatross, which is met with in the southern seas, is one of the largest, and perhaps the most efficient, of the sailing birds, and like the gull makes a practice of following ships, obtaining lift from the rising currents caused by the ship's displacement of the air and the heat emitted from the funnels and other openings. Effortless flights of many days duration are made in this manner.

Vultures, condors, eagles and kites are found chiefly in mountainous and tropical countries, and depend on the ascending currents due to the hills or convection. Their habit is to soar slowly upward, generally in a spiral fashion, often reaching great heights, and then to descend at an extremely fine gliding angle in any desired direction to some other source of up current, where the process is repeated. In the cases of flights over tropical planes these are confined to the hours during which the sun is shining.

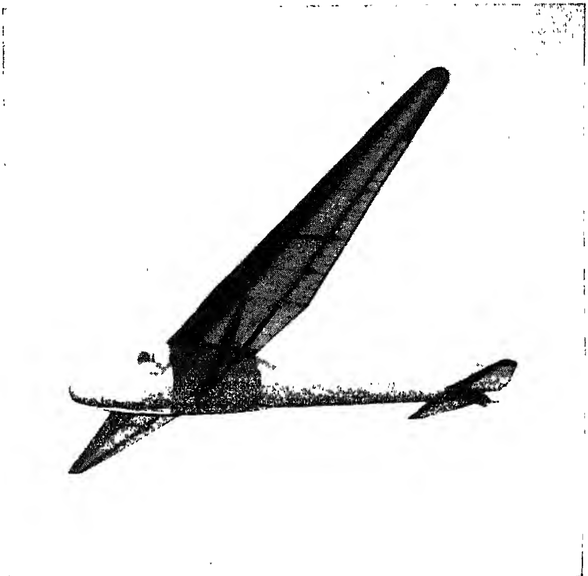


FIG. 58.—The " Wien."

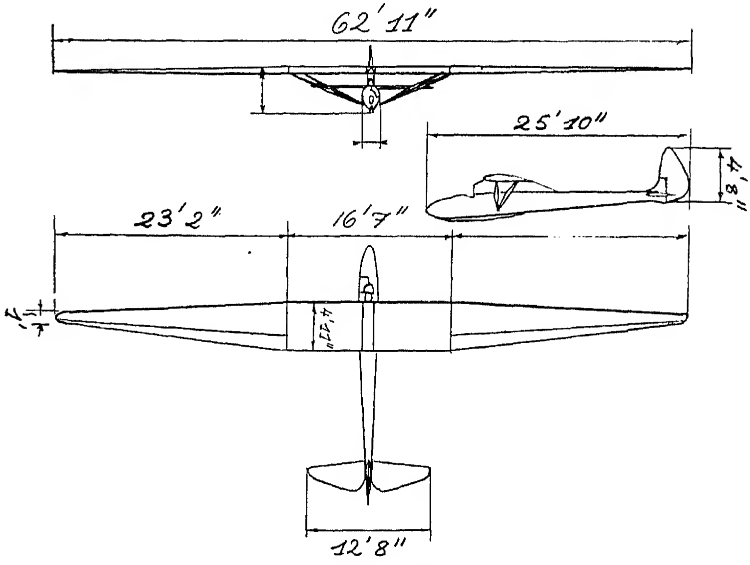


FIG. 59.—The " Wien."

[*To face page* 113.

CHAPTER IX

Sailplane Types

Wien—Schloss Mainberg — Kakadu—Luftikus— Rhönadler—Fafnir—Austria — Albatross — R.F.D. Sailplane — B A.C. 7 — Phantom — Tern—Scud—Table of Particulars.

The most successful sailplanes to date have been produced in Germany and are the outcome of many years steady development. The descriptions given below are of sailplanes of greatest achievement and interest.

The "Wien"

The "Wien" was built for the 1929 international competition, for Kronfeld, and was the winning machine of the meeting. The design was based on the "Professor" type with an improved aspect ratio of 20 and a span of 62′ 10″.

The wing, of semi-cantilever construction, was built in two parts only, joining at the centre, for ease of erection and to avoid the weight of extra fittings. The section is Göttingen 549, but has the central parallel portion more strongly cambered for increased strength. The outer portions taper both in chord and camber to the tips, where the chord is slightly less than 1 ft.

The wing is of the single spar type, with a torsion resisting leading edge covering, but has a light rear spar for general stiffness and the aileron attachment. The central rectangular portion, between the strut attachments, is little more than one-quarter of the span. The lift struts form a "V" and attach to the fuselage with one pin on each side.

The fuselage is monocoque of oval cross section and with a small frontal area tapering finely to the tail. The good flying qualities have been largely ascribed to the differential aileron control.

A small vertical fin acts as a support for the rudder, but there is no fixed tail plane.

The "Schloss Mainberg"

This machine is also a development of an earlier successful type, the "Westpreussen," and is a cantilever of single spar construction.

The wing is in three almost equal sections, giving a total span of 52′ 6″, is elliptical in plan shape, and attaches directly above the fuselage so that the pilot's head is just in front of the leading edge. The section is Göttingen 535.

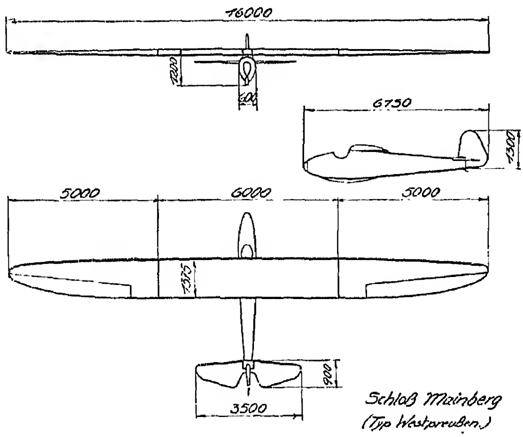


Fig. 60.

The fuselage is rather short, of plywood construction, and oval section. A small horizontal fin is built-in, at the rear of the fuselage, which serves as a support for the elevators. Owing to its small size it can hardly be called a tail plane.

The Darmstadt II, or "Starkenburg," is a slight variation of the Schloss Mainberg. The outside dimensions are similar, but a different wing section is employed.

The "Kakadu"

The "Kakadu" has proved itself to have a performance almost as good as any other yet produced.

The wing has fairly similar dimensions to the "Wien" and is of R.R.G. 652 section. Horn balances are supplied to the ailerons at the wing tips, a rather unusual feature with

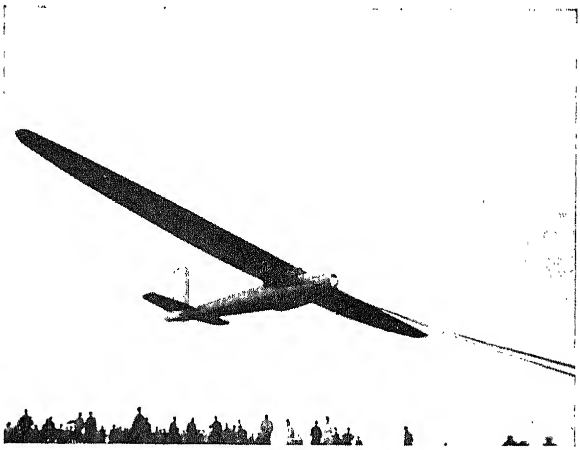


FIG. 61.—" Darmstadt II."

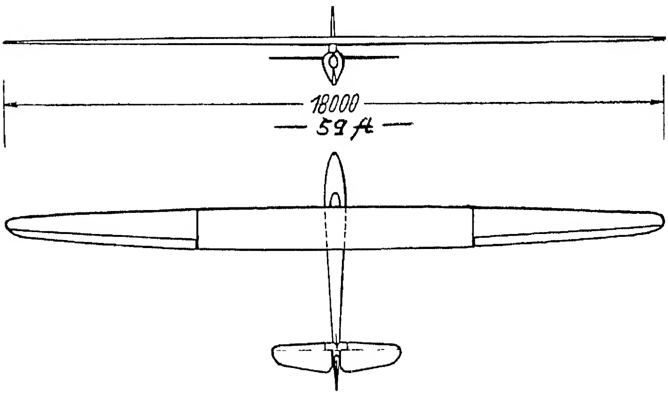


FIG. 62.—" Darmstadt II."

To face page 114.

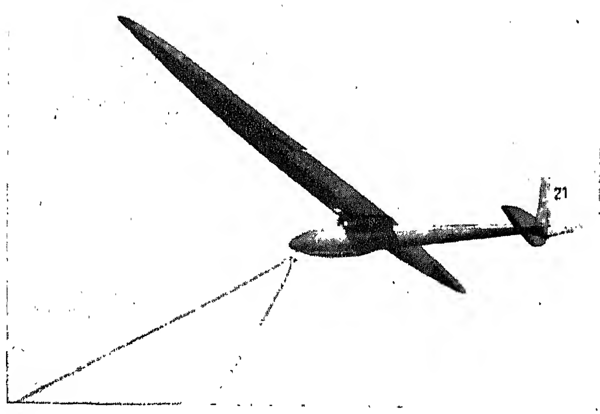


FIG. 63.—" Kakadu."

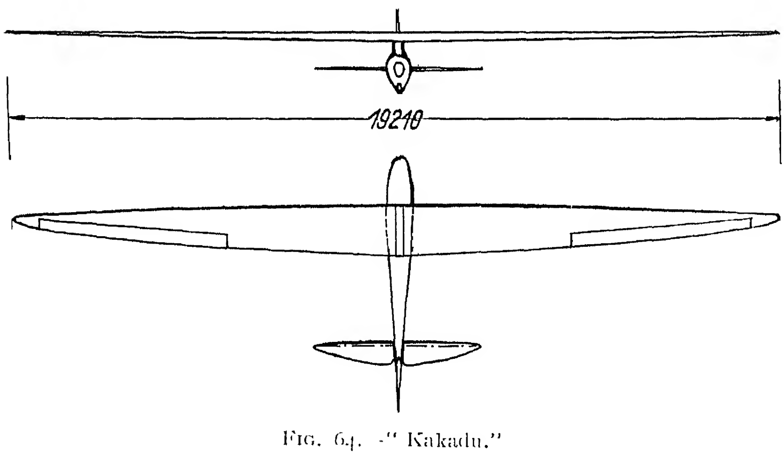


FIG. 64.—" Kakadu."

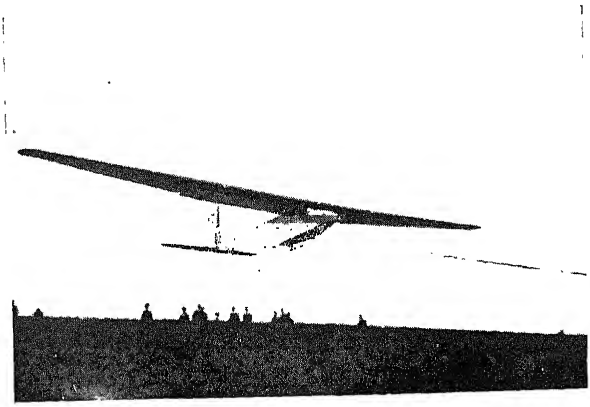


FIG. 65.—" Luftikus."

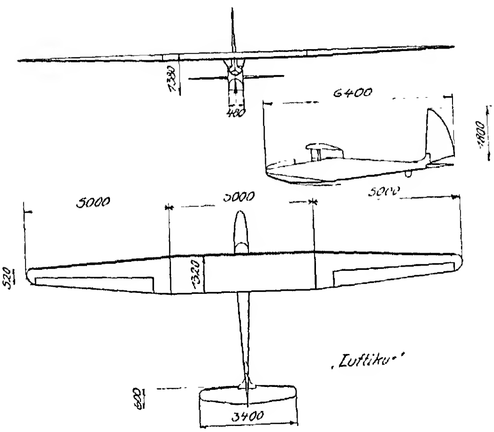


FIG. 66.—" Luftikus."

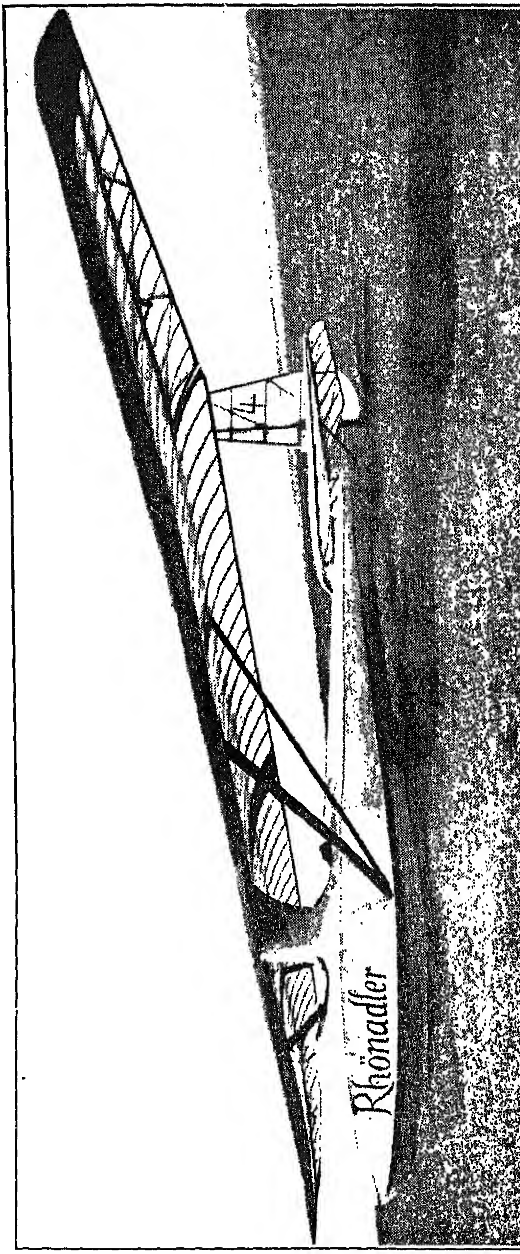


FIG. 67.—Two-seater Sailplane, "Rhönadler."

[To face page 115.

sailplane design, but the liability to damage makes this of doubtful value.

The wing construction is of the single spar type with torsion tube. The heavy wing weight, amounting to nearly 1.5 lbs. per sq. ft., causes the planes to flex considerably in flight during gusty weather.

"Luftikus"

The "Luftikus" would not appear to be as efficient as some of the other types on account of its square shaped fuselage, but actually it has proved itself to be one of the best, and seems to show that the most expensive fuselages, of oval monocoque construction, are not absolutely essential for good results.

Göttingen 535 section is employed for the wing, which is cantilever except for very short steel tubular struts running out from the top of the fuselage on either side. The wing is in three equal sections and has one spar together with an auxiliary spar in the central portion.

The fuselage is built up on four longerons with plywood sides forming a square, but additional fairing forward of the main plane brings the shape to hexagonal. At the rear the fuselage forms a horizontal edge and is built out to make a small fin to which the one-piece elevator attaches.

The maximum width of the fuselage is less than 19″ and is too narrow for comfort during long flights.

The "Rhönadler"

This machine is one of the most successful two-seater sailplanes.

The wing, of R.R.G. 652 section, has an area of 290 sq. ft., with a 57′ 3″ span, and is made in two parts, with "V" lift struts supporting the central rectangular length.

Beyond the strut attachments the planes taper to the tips, where the section changes to a thin slightly cambered wing section.

The wing is built up on two deep "I" section spars, in the forward half of the chord, connected by ply covering, above and below, to form a torsion resisting box, together with a light rear spar.

Apart from the " V " struts, the wing rests on a high " neck " between the cockpits and is wire braced from the front strut attachment at the wing to the nose of the fuselage.

The fuselage is of hexagonal shape, built up on 6 longerons faced with plywood and forming a small fin at the sternpost for the rudder attachment.

A fixed tail plane is supported just above the fuselage with struts and is fitted with divided elevators.

The " Fafnir "

The " Fafnir " was designed for the 1930 competitions as a development of the " Wien," which in turn had been developed from the " Professor."

The machine is of cantilever construction. The main plane rests just above the fuselage, the central portion being built to form a dihedral angle, with the outer portions horizontal. The dihedral lifts the wing tips higher off the ground, whilst the horizontal outer sections are intended to provide better aileron control than would be available if the dihedral were continued right out to the tips.

When in the air, the break in the line of the wing gives the appearance of down-turned wing-tips and resembles very closely the seagull.

The pilot's head is completely faired in to prevent air disturbance over the wing, in its rather low position, and at the same time to reduce head resistance.

The wing section is Göttingen 652 at the centre, changing to 535 and again to Clark Y at the tips. The tips are, therefore, of symmetrical section to prevent stalling and to increase the effectiveness of the aileron.

Three spars are used for the wing. The centre spar, at about one-third chord from the leading edge, is the main spar and is of box section, whilst the others are approximately one-sixth and two-thirds of the chord from the front and are of " I " section.

The construction results in a heavy machine, of 400 lbs. weight empty, but this does not appear to have an adverse effect, in fact under certain conditions it is advantageous for cross-country work. The " Fafnir " handles very well, has a very pretty appearance and has carried out some remarkable flights.

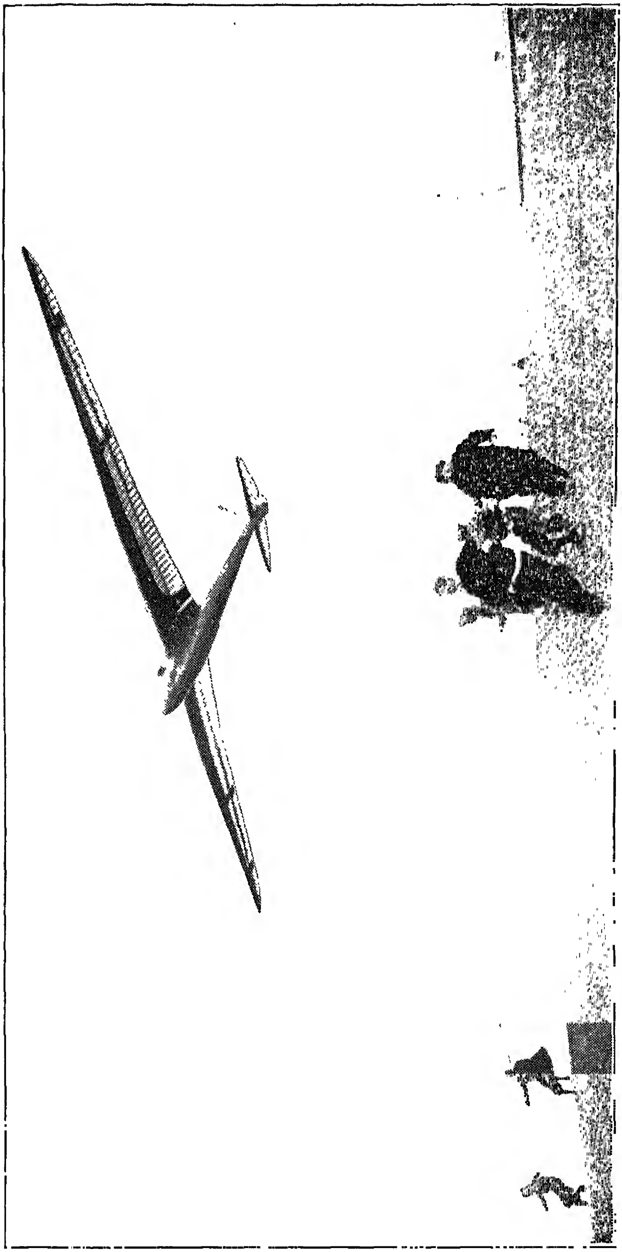


FIG. 68.—The "Fafnir."

[*To face page* 116.

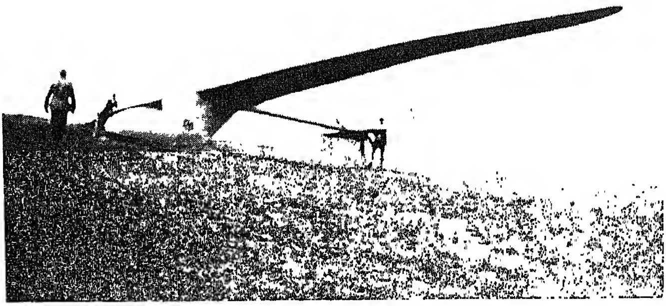


FIG. 69.—The " Austria."

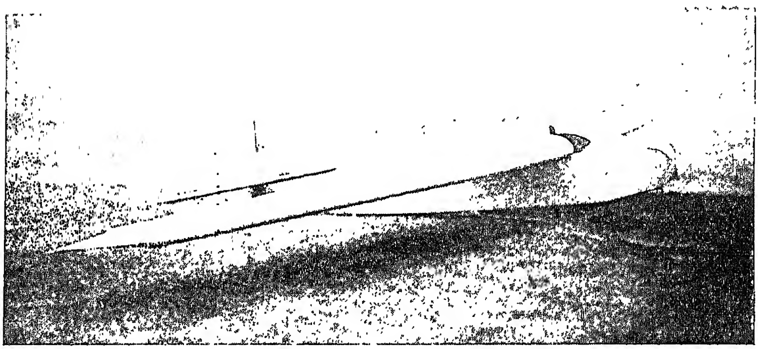


FIG. 71.—The " Albatross."

The "Austria"

This is the largest sailplane ever built and has a span of 100 ft. The wing is in four sections, the outer sections being set at an anhedral angle. There is one main "I" section spar and one secondary spar, and plywood is used almost entirely for the wing covering.

Ailerons which run the entire span are divided into six sections and can be adjusted to work differentially in pairs.

A nacelle to house the pilot and fitted with the main skid is built below and forward of the main plane, the connection being by a very long "neck." Just below the wing and at the top of the neck is a large tubular plywood covered boom which tapers to about 1 ft. in diameter at the rear where it is widened out to form the tail plane.

Behind the tail plane is a one-piece elevator, and at each end are built-in fins, to which rudders are hinged.

The two rudders can be actuated together to form an air brake, but for turning are used independently. The bottom edges of the fins act also as skids.

The wing area is 323 sq. ft., and the all-up weight is in the neighbourhood of 1,000 lbs., giving a loading of about 3 lbs./ sq. ft. and an aspect ratio of 31.

The "Austria" was designed for Kronfeld by Dr. Kupper.

Descriptions of two German tailless sailplanes were given in the last chapter. (See Figs. 46 and 47.)

The "Albatross"

This machine, built by the R.F.D. Co. to designs by the author, was the first British sailplane and was based more on the design of light aeroplanes than gliders. The "Albatross" was built for extreme lightness, with an empty weight of little over 200 lbs. This factor resulted to some extent in a lack of robustness necessary for rough handling and for soaring in gusty weather.

Despite this, several soaring flights have been made, including a short storm flight.

A short centre-section plane is connected immediately above the square section fuselage, to which the two outer portions, each of 19 ft. span, attach. The total span is 42 ft., and is pure cantilever.

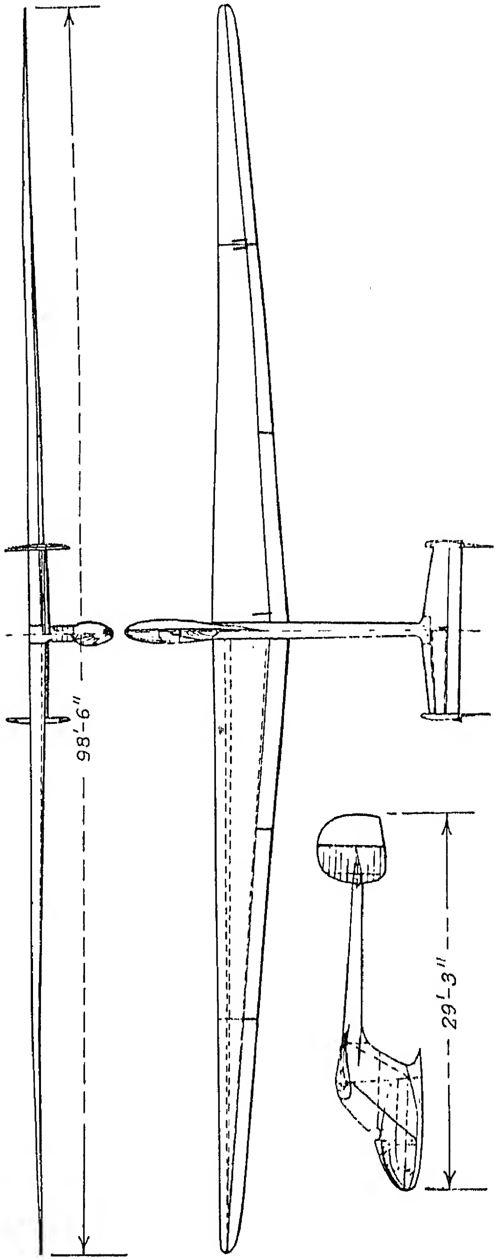


Fig. 70.—The " Austria."

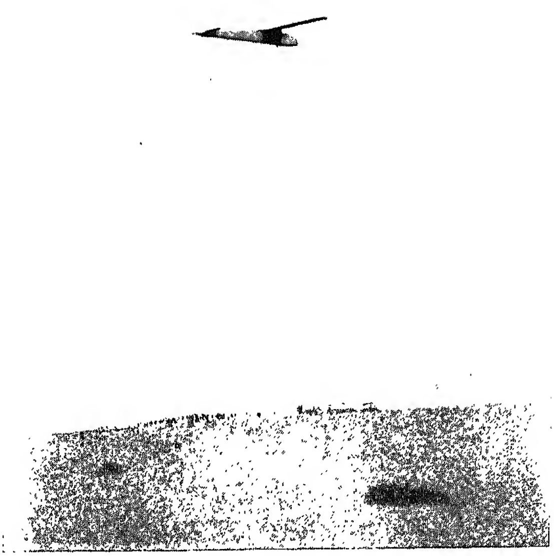


FIG. 73.—The R.F.D. Sailplane.

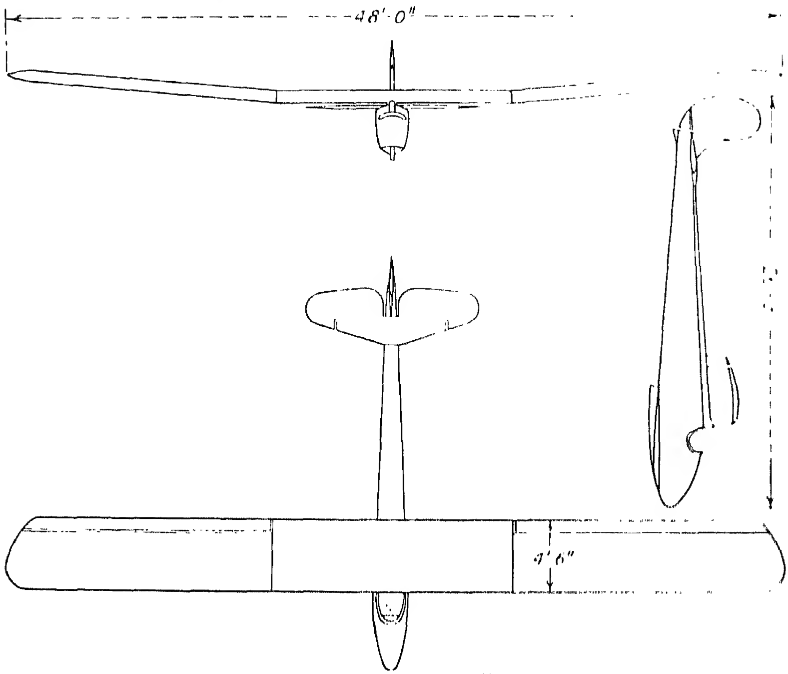


FIG. 74.—The R.F.D. Sailplane.

[To face page 110.

The central third of the main plane is rectangular, after which it tapers to the tips. Göttingen 535 is used for the aerofoil section.

Two spars are employed in the wing, the forward spar being of " N " girder construction, for lightness, and the rear spar of box section.

There are no fixed tail surfaces, the balanced elevator being in one piece and supported above the fuselage, whilst the rudder is also balanced and attaches to the vertical edge formed by the rear of the fuselage.

The "R.F.D." Sailplane

This machine was built to the design of Mr. J. Bewsher by the R.F.D. Co., of Guildford.

The cantilever wing is built in three parts, of almost equal length, giving a span of 48 ft., and with the outer portions set at a dihedral angle.

There is one main spar, of triangular section, employing three flange members covered on the outside with plywood for torsional resistance, the spar joints being made by means of turnbuckles.

There is no taper to the wing, but the tips are rounded. Ailerons of small chord run the entire length of the two outer portions of the wing.

The fuselage is pear shaped with the thicker part uppermost, and the wing is supported directly above, these connections also being by turnbuckles.

The loaded weight is 410 lbs., giving a wing loading of less than 2 lbs./sq. ft., the wing area being 210 sq. ft.

A tail plane is attached above the fuselage, to which is hinged the split elevator, and behind this is a vertical fin and unbalanced rudder.

The "B.A.C. 7"

This is a two-seater sailplane built by the British Aircraft Co., of Maidstone.

The wing is in two parts and is connected on each side by two parallel struts to the underside of the fuselage. It is of normal construction, employing two main spars. Beyond the struts the wing tapers; rather small ailerons being fitted along the tapering portion only.

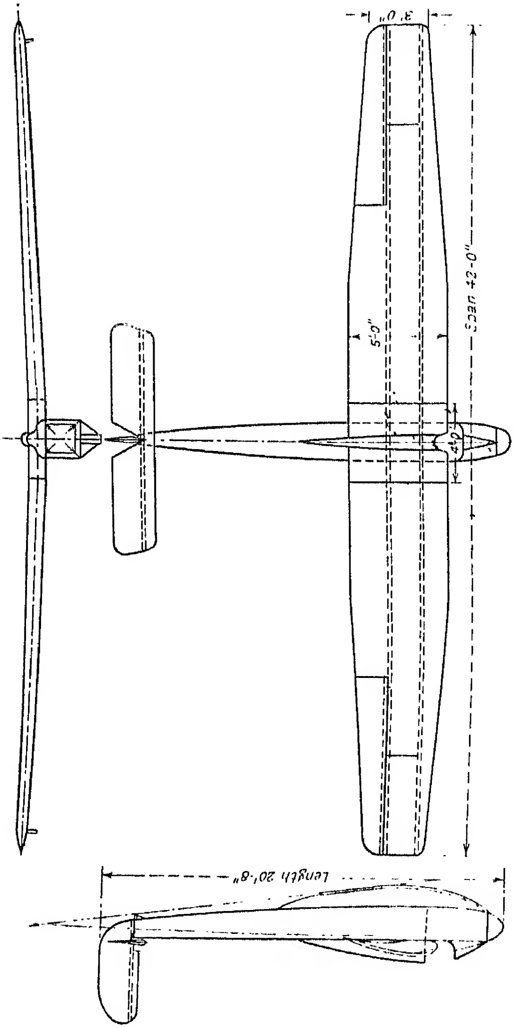


FIG. 72.—The "Albatross."

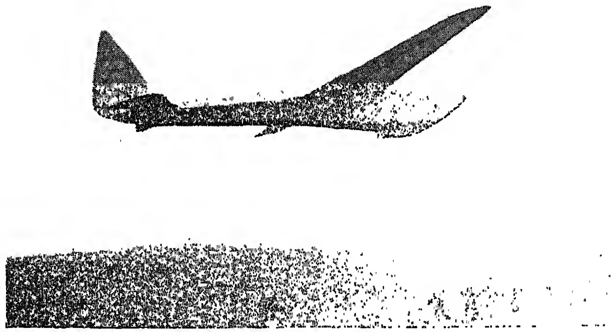


FIG. 75.—The "Tern."

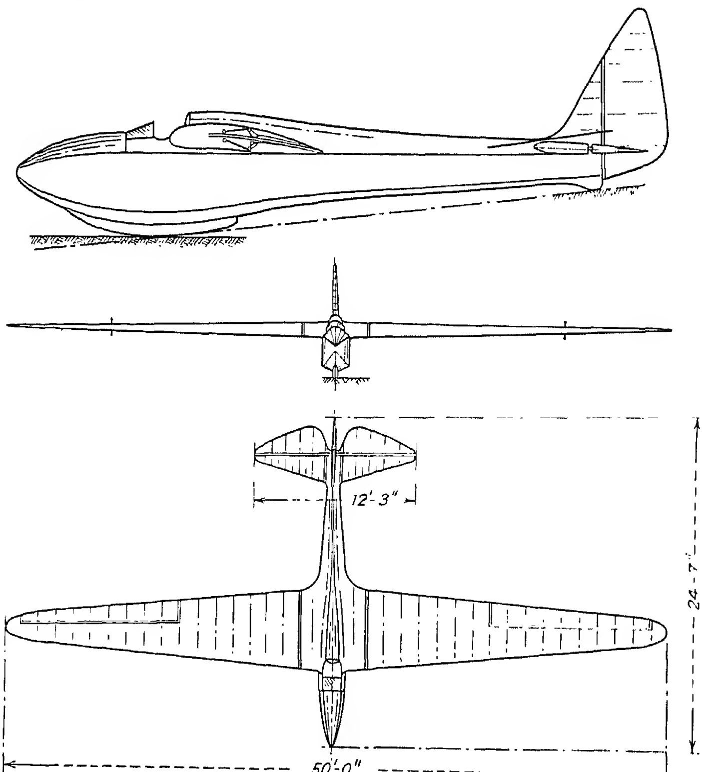


FIG. 76.—The "Tern."

[*To face page* 121.

The fuselage is built up on four longerons, but has a raised portion on top to act as fairing behind the pilot's head. Plywood covering is used. The attachment of the wing with the fuselage is made by two pillars joining the main spars to points between the two cockpits and behind the rear cockpit.

A small vertical fin is built in to the rear end of the fuselage, and a split tail plane attaches on either side with short struts to the bottom longeron. The rudder is slightly balanced, but the elevators are not.

For auto- and aero-towing a wheel undercarriage is fitted.

The B.A.C.6 is a similar machine, differing in small details only, but is a single-seater.

The "Phantom"

The "Phantom" sailplane was manufactured by the Cloudcraft Glider Co., of Southampton, in 1931.

The wing is of single-spar construction, and is supported by one strut on each side of the fuselage and a raised "neck."

The monocoque fuselage is of fairly large cross sectional area and length. A small horizontal fin is provided at the end for the elevator attachment, resembling closely the Darmstadt type of design, and a large rudder, of area equal to the elevator, is hinged to a small built-in fin.

R.A.F. 34 aerofoil section, modified, is employed for the wing, which has an area of 200 sq. ft. and a span of 51 ft. The loaded weight is low, at 407 lbs., giving a wing loading of about 2 lbs./sq. ft.

The "Tern"

This is one of the latest British sailplanes, and was constructed by Messrs. Airspeed, Ltd., of York. It is a pretty design and incorporates several unique features.

The wings are of normal two-spar construction and taper over the whole span, with the percentage camber increasing towards the root. A short centre-section plane is built-in to the top of the fuselage, and to this the outer sections are held by two vertical bolts in each plane.

The fuselage, of plywood construction, is large and roomy, with a comfortable cockpit for the pilot.

An important feature of the "Tern" is the rapidity with which it can be assembled, and this is largely due to the fact

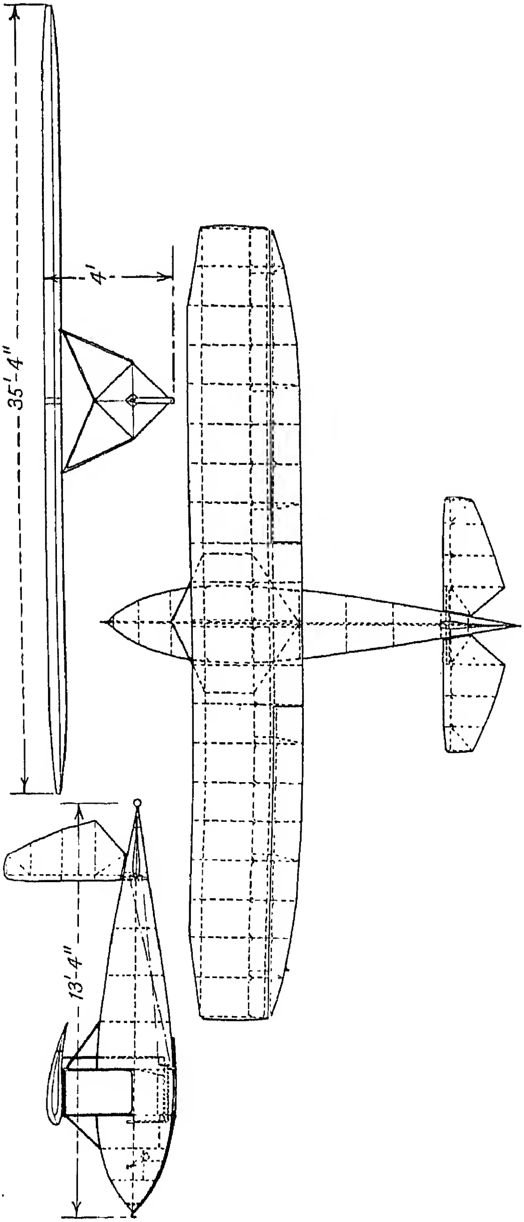


Fig. 78.—The "Scud."

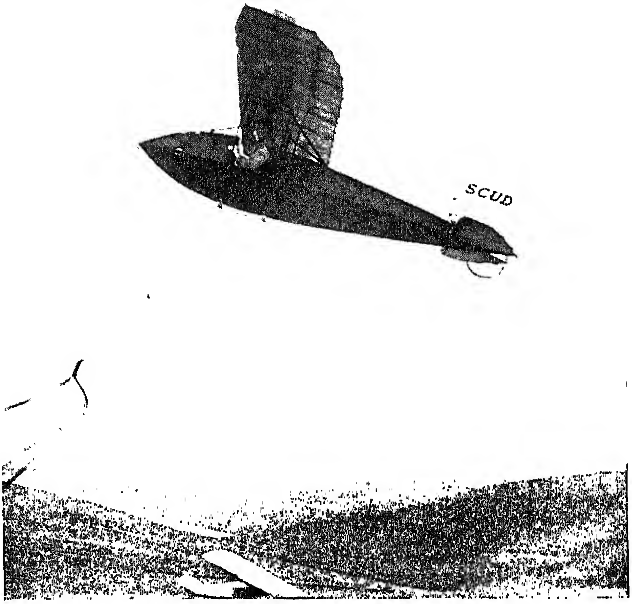


FIG. 77.—The "Scud."

[*To face page* 123.

that no control mechanism has to be connected up or adjusted. Both the aileron and the elevator controls automatically interlock as the units are assembled into position.

The "Scud"

The "Scud" is really an intermediate sailplane, but is included here on account of its unique features and minute proportions, in comparison with other sailplanes.

It was designed by Mr. L. E. Baynes, and is manufactured by Messrs. E. D. Abbott, Ltd., at Farnham, Surrey.

The cantilever wing has a span of 25′ 4″, with an area of only 85 sq. ft., giving an aspect ratio of 7.5. The unladen weight is 103 lbs., and, allowing 150 lbs. for the pilot, the wing loading is 3 lbs./sq ft. Owing to its extremely small weight it is very portable and can be carried by four men with ease.

The main plane is of modified Göttingen 535 section, is of two-spar construction, with plywood covering from the leading edge to the rear spar, and is in two halves which join at the centre before attachment to the body. The wing support consists of eight small steel tubes joining to the fuselage longerons.

The fuselage is of square section, set on edge, and is built up on four longerons with plywood covering.

The elevators and rudder are interchangeable and quickly detachable. No fixed tail surfaces are provided. Narrow chord ailerons run almost the entire wing span, and are operated by means of torsion tubes.

The pilot's seat is immediately below the wing.

Despite the heavy wing loading and small aspect ratio the machine soars well, at a speed not unduly high, and is very responsive on controls.

Table 4 on page 124 gives the leading dimensions and particulars of the sailplanes described. Every care has been taken in its preparation to ensure accuracy.

TABLE 4

Name of Sailplane.	Total Weight, lbs.	Wing Area, sq. ft.	Wing Loading, lbs./sq. ft.	Span, ft.	Aspect Ratio.	Length.	Wing Section.	Type.
Wien	533	194	2.75	62′ 10″	20	2[illegible]′ 10″	Göttingen 549[1]	Semi-Cantilever.
Schloss Mainberg	460	183	2.56	52′ 6″	15	20′ 3″	Göttingen 535	Cantilever.
Kakadu.	526	190	2.77	63′	21	—	Göttingen 652	Cantilever.
Luftikus	473	166	2.85	49′ 3″	14.6	21′	Göttingen 535	Cantilever.
Rhönadler	735	290	2.53	57′ 3″	12.2	26′ 4″	Göttingen 652	Semi-Cantilever.
Fafnir	550	200	2.75	63′	20	25′ 10″	Göttingen 652 Göttingen 535 Clark Y	Cantilever.
Austria	1,034	376	2.75	98′ 6″	26	29′ 3″	Göttingen 652[1]	Cantilever.
Albatross	360	180	2	42′	10	20′ 8″	Göttingen 535	Cantilever.
R.F.D. Sailplane	410	210	1.95	48′	11	26′ 3″	—	Cantilever.
Tern	415	201	2.06	50′	12.4	24′ 7″	—	Cantilever.
Scud	253	85	3	25′ 4″	7.5	13′ 4″	Göttingen 535[1]	Cantilever.
Phantom	407	200	2.04	51′	13	25′	R.A.F. 34[1]	Semi-Cantilever.

[1] Modified.

PART II

SAILPLANE CONSTRUCTION

CHAPTER X

The Main Plane

Main Plane Construction, General—The Main Spars—Ribs—The Leading Edge and Trailing Edge—Ailerons—Lift Struts.

Main Plane Construction, General

The main planes, or wings, of a sailplane consist of the main spars, ribs, leading and trailing edges, ailerons, and drag bracing or its equivalent, and are built in two, three, or even four, separate parts. Machines have been constructed with a single unit wing, but this is seldom done owing to the difficulty of housing and transporting so large a span.

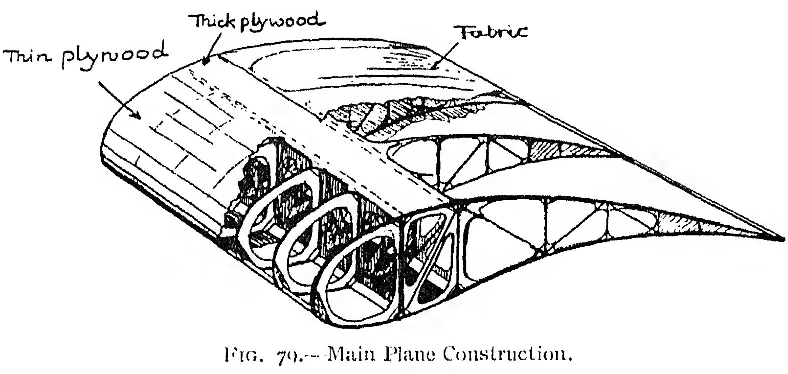


Fig. 70.—Main Plane Construction.

Two of the essential features of sailplanes are, firstly, the requirement of quick detachability, or folding, and secondly, compactness, when dismantled, for towing purposes in a trailer, and for storage, and it is these factors that govern the number of parts into which a sailplane dismantles. Some machines have a two-piece wing, with the joint at the centre, but this is not convenient for spans of over 40 ft., 20 ft. being a reasonable limit for each part, nor does it permit of simple

construction for cantilever wings, and it is, therefore, much more general for wings to be made in three parts of approximately equal length and giving a total span of between 50 and 60 ft.

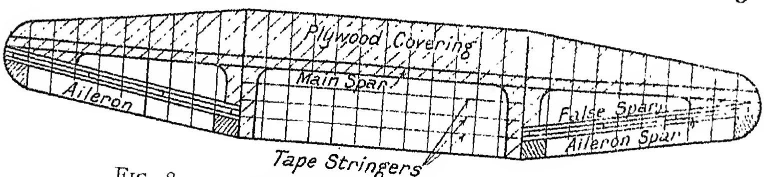


FIG. 80.—Typical Lay-out for Sailplane Main Plane.

The Main Spars

There are generally one or two spars in wings of sailplanes, though three have been used, whilst the multi-spar system also has been employed. The use of three spars appears unnecessarily heavy, and difficulty has been experienced owing to undue deflection of multi-spar type wings.

When only one spar is used, the torsion, due to the centre of pressure not coinciding with the spar position at all attitudes of the machine, is rather severe, and to allow for this it is usual practice to cover the whole of the surface, forward of the spar, with a stiff covering, generally plywood, and to anchor the leading edge to the body so as to transmit the torsion to the fuselage. This covering serves a double purpose since it also ensures a good shape being retained by the front part of the main plane which, in itself, is a valuable feature and, for this reason alone, the construction is generally applied to all wings.

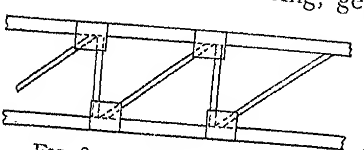


FIG. 81.—" N " Girder Spar.

Single spars are placed at approximately one-third of the chord back from the leading edge.

Spars may be of either built-up " I " section with split flanges and plywood webs, the simplest and cheapest construction, or of box section, in which plywood webs are glued to a pair of spruce flanges. (See Fig. 32, Part I, Chapter III.) The latter method possesses much higher torsional resisting properties, although this is not of so much importance where stiff leading edge covering is used, but its use is recommended

for single spar wings, as in the event of the leading edge ply being damaged a box spar is better able to stand the additional torsional load.

Box spars should be blocked at the ends and at every few feet of length for rigidity, besides which small blocks should be inserted at the attachment points of all fittings. After gluing up of box spars, or even before, small holes should be drilled along the neutral axis of the webs to allow for the escape of moisture. There should be one hole between each pair of blocks.

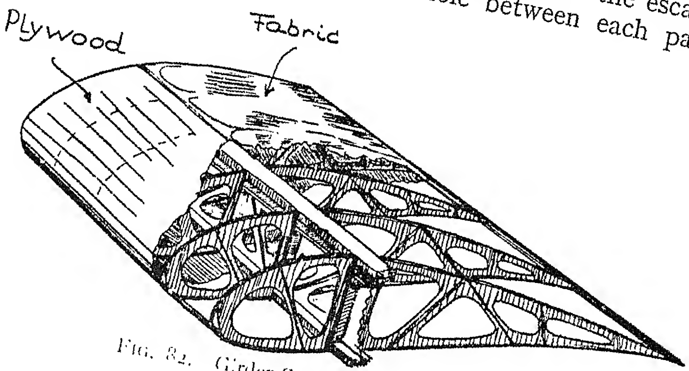


FIG. 82. Girder Spar and Plywood Ribs.

Another type of spar is the built-up "N" girder, consisting of flanges separated by vertical struts and diagonal bracing pieces, with plywood gussets at all joints (Fig. 81). Although this method calls for accurate workmanship it affords a very light structure and, if thin plywood webs are substituted for the gussets, the spar has the combined qualities of the box and girder types.

Where a single spar is employed the ribs should be held from sideways movement by tape stringers, parallel to the spar, spaced at about every 6 or 8 in. and bound round each rib boom. This adds very little weight and gives remarkable rigidity to the whole wing.

Ribs

Sailplane ribs are almost universally built up of rectangular sectioned flanges, or booms, and cross pieces, the "I" section so well-known in aeroplane work being very seldom used on

account of the light stresses due to the low wing loadings. Flanges and struts call for quite small sections, $\frac{1}{4}'' \times 3/16''$ being quite common, and even as small as $3/16'' \times \frac{1}{8}''$ being not unknown. Simple construction with small ply gussets at the joints suffices, but a method, much favoured in Germany, is known as the " split rib," in which all members are halved through the central plane of the rib with the gussets inserted between the half members, as shown in the sketch, Fig. 84.

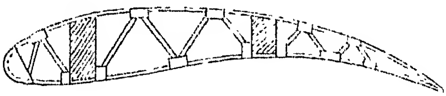


FIG. 83.—Main Plane Rib.

The advantage of this method is that the rib can be built up in a jig, without the necessity of removal after gussets are fitted to one side and changing over for attaching the gussets on the reverse side. There is, however, a drawback to the method in that the rib members are weakened, and to overcome this to some extent the halves are sometimes pulled in together at the centres and glued.

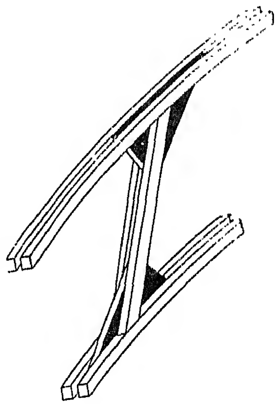


FIG. 84. Split Type Rib.

Rib spacing should be kept fairly small, so that the profile of the wing section is not allowed to become distorted, by arching between the ribs, and intermediate ribs, such as is shown in Fig. 85, can be usefully employed in planes having two main spars. It is a mistake to economise in weight by reducing too far the number of ribs, as the total weight of ribs in one machine is a very small amount, and another one or two make very little difference in this respect.

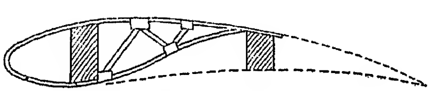


FIG. 85.—Light Intermediate Rib.

The nose of the rib may be built up in a similar way to the remainder, although, owing to the large curvature of aerofoils used in cantilever wings and the difficulty of bending the rib boom to this shape, it is quite common to replace the front part of the booms with a plywood nosing piece. This also has the effect of stiffening up the ply covering on the leading edge.

Another method of rib construction is to cut a three-ply web to the exact aerofoil shape, lightened by holes for preference, and to attach split flanges around the edges. Some vertical stiffening pieces should be included. This is a more expensive method as regards material, and the resulting rib may be somewhat heavier, but it can be made in less time and provides quite a strong rib.

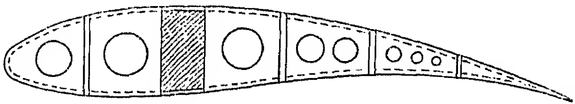


FIG. 86.—Rib with Strengthened Plywood Web.

The Leading Edge

This has already been referred to in the paragraphs dealing with spars and ribs, in which it was stated that the general practice is to cover the front portion of the wing with plywood to retain the correct aerofoil shape and to stiffen this up with nosing pieces at each rib.

For strongest results the plywood should be laid on diagonally, that is to say, with the grain at an angle of $45°$ to the leading edge (see Appendix VII). Thick plywood should be damped, on one side only, and left for some minutes before fixing. It will then take the required shape more easily and facilitate the work of fixing.

Apart from this covering, the actual leading edge member is quite small and may take a rectangular shape, of section $\frac{3}{8}'' \times \frac{3}{4}''$, or thereabouts, with the longer axis parallel to the chord. This is often strengthened up at the ends where joints in the wings take place, both for stiffness and to supply better anchorage for the connecting fittings.

The Trailing Edge

Flight requirements call for very little strength in this member, so that it is designed mainly for keeping the fabric taut and for rigidity for handling during dismantling, assembly and storage.

Fig. 87 shows three types of trailing edge commonly used, (*a*) and (*b*), consisting of a strip of three-ply, strengthened up with a piece of spruce, or ash, whilst (*c*) is a plain lath to which the rib flanges are attached.

Attachment may be made by glue alone, or with brads, or by small light metal clips.

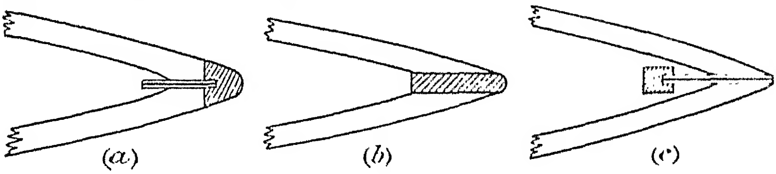


FIG. 87.—Types of Trailing Edges.

Other forms of trailing edge are light metal tubes of round, or, preferably, flattened section, or metal sheet bent into "U" or "V" shape, but these last methods are not used to any great extent in sailplane work.

The trailing edge may also be stiffened up by strips of ply above and below the rib flanges, and if these are cut so as to leave small forward extensions at each rib, the robustness of the whole wing structure is increased.

The Wing-Tip

The wing-tips of sailplanes are called upon to fulfil several duties, and should be robustly built accordingly. They are subjected to handling loads, during assembly and when the machines are being towed, or carried, into position for launching.

During landings, sailplanes sometimes first touch the ground on one wing-tip for swinging into wind, and often meet obstructions near the ground, such as small bushes and rocks.

The wing-tip member is generally of fairly heavy section, say one inch square, and rounded on the outside, but may be spindled from the inside for lightness. Plywood covering may be placed over the wing-tip and fixed to the last rib and the wing-tip member. The box thus formed makes a very strong wing-tip. (See Fig. 88.) The wing-tip member should be of ash, steamed to shape, or of laminated ash.

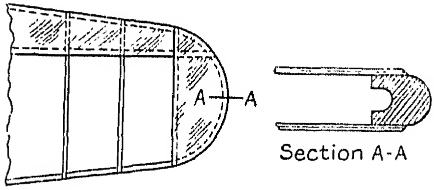


FIG. 88.—Wing-tip Details.

In some cases, such as on the "Professor," the wing-tip member is shaped to conform with the wing section, as shown in Fig. 89 (*a*), whilst an alternative is to cut plywood to the shape of the wing-tip and strengthen, on top and underneath, with light strips of ash, or other suitable material, bent to shape, as at (*b*).

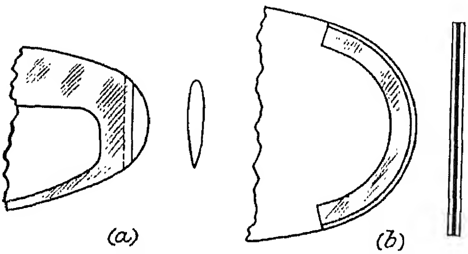


FIG. 89.—Wing-tip Construction.

Ailerons

Ailerons may, for convenience, be built as a whole with the main planes and sawn off afterwards.

The ribs follow the standard practice, but may, if desired, be triangulated, as shown illustrated, Fig. 92. The advantage of this is that much of the torque is transmitted through the ribs instead of along the spar and also rigidity is given to the whole unit.

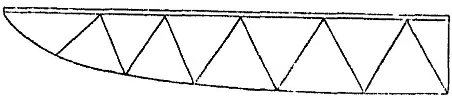


FIG. 90. Aileron with Triangulated Rib Arrangement.

The spars are generally of box section, owing to the torsional strength of this design, but are sometimes built up of two small flanges and one web, as shown in Fig. 91 (*b*). This type is not strong torsionally, and is also difficult to calculate for torsional strength, although actually the attachment of the ribs overcomes this weakness to a certain extent, especially as it is usual to attach a vertical member, connecting both flanges, at each rib joint. The semi-cylindrical plywood fairing, described below, also assists in this respect. Tubular metal spars, for ailerons, are not greatly favoured for sailplanes, owing to the difficulty of rib attachment.

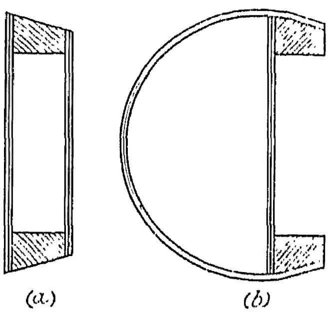


FIG. 91.
Types of Aileron Spars.

In order to prevent the interruption of air flow over the aileron gap a strip of thin plywood may be attached to the front of the aileron spar in the form of a half cylinder (see Fig. 92), and should be held in shape by small formers spaced at about every foot or 18 in.

The tube thus formed is often made to take the torsional stresses, in which case a light spar can be employed for taking the bending loads only.

Corresponding small fillets should be fitted to the main plane or false spar so that the aileron works nicely in the groove thus formed These fillets may be made of balsa wood for lightness or, if of a better wood, they may be taken into consideration for strength purposes, as with the plywood on the aileron spar.

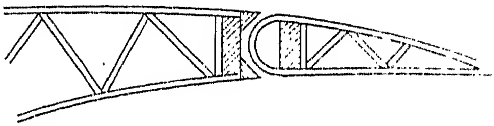


FIG. 92.—Aileron Gap.

Strips of plywood, or celluloid, are often attached along the top and under-side of the main plane spar, so as to cover the gap between that and the aileron. This is a simple method, but it is doubtful whether it is as efficient as the previously described method, owing to possible cockling of the ply and the discontinuity of profile that must be caused with movement of the aileron.

When single-spar main plane construction is used, or when the aileron hinges are located some distance behind the rear spar, it becomes necessary to include a false spar. This may be of light construction, as it has to take the direct loads only from the aileron and distribute them to the main spar, either direct or through the ribs.

The false spar generally runs the length of the control surface only, but may be extended for a short distance if there happens to be a strong member, such as a box or compression rib, for attaching the spar end to.

When possible it is sound practice to attach the outer end of the aileron false spar to the main plane spar tip, as this forms a triangle, giving considerable torsional resistance and stiffness

to the wing. This is shown illustrated in the figure on page 128.

Lift Struts

The type of strut most favoured for sailplane work is the composite timber strut, consisting of a rectangular spruce member, with its long axis in the lateral plane of the strut, and with plywood fairing over suitably spaced formers. (See Fig. 93.) The main spruce member prevents failure in a sideways direction, while the plywood shell provides sufficient strength against fore and aft failure.

This provides a strong light strut, is very suitable for the requirements, and is cheap to produce.

Other types are the steel or duralumin tubes, either of streamlined section or of circular section with wooden fairing, this latter being a cheaper construction than the former.

Solid spruce struts are sometimes used but are relatively heavy.

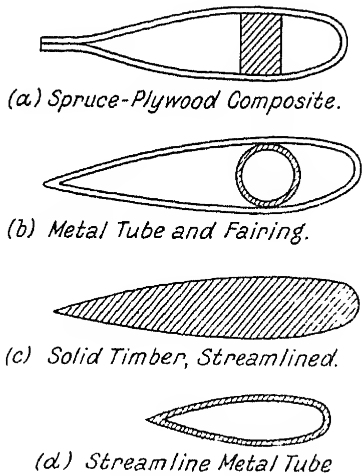


FIG. 93.—Types of Lift Struts.

Finish

The weights of the wings on each side of the fuselage should be evenly balanced, as wings of unequal weight tend to cause spinning when stalled. For this reason components should be weighed during manufacture and balanced out.

Main planes are covered with a good quality light, closely-woven fabric, or silk. This is generally held to the spars, ribs, etc., by glue or dope, after which it is treated with four or five coats of transparent dope, each coat being allowed to dry thoroughly before applying the next coat, and finished off with one thin coat of good varnish.

Smoothness of surface is of the utmost importance.

CHAPTER XI

FUSELAGE AND EMPENNAGE

Fuselage Construction, General—Monocoque—Braced-Strut or Girder Type—Skids, Main and Tail—Tail Unit.

Fuselage Construction, General

THE outline shapes of fuselages have already been dealt with in Chapter II, page 26. There are two methods of construction; the monocoque, which consists essentially of a large stiff tubular box in which practically the whole of the stresses are taken by the covering material, and the normal braced strut type, consisting of longitudinal members divided into bays by vertical and horizontal struts with cross bracing, the whole being covered with fabric.

Another method, which is really a simple combination of both, employs longitudinal members placed in the form of a square or hexagon, with flat sides between the longerons covered with three-ply or multi-ply.

Monocoque

Some longitudinal members are generally used in this method of construction to give stiffness to the whole and for ease of building, but they need be of only quite small section. Fig. 94 shows a typical section employing three longitudinals, a fourth sometimes being inserted at the top, as shown dotted. The bottom longitudinal member or the keel may take the shape of the fuselage bottom, and is sometimes divided into two and spaced a distance apart equal to the main skid over the skid portion of the length.

Main bulkheads are placed about every 12″ or 18″, and consist roughly of $\frac{1}{2}'' \times \frac{1}{2}''$ circular members built up from several pieces, or one piece bent to shape, and faced both sides with three-ply cut to the shape of the fuselage section and of about $\frac{3}{4}''$ or 1″ deep.

Intermediate stiffeners are spaced every 6″ or so, and are generally of very small section, say $\frac{3}{8}'' \times \frac{1}{8}''$, with the longer dimension in the direction of the fuselage axis.

The bulkheads at the main spar attachments are of heavier and more intricate construction, of the form shown in Fig. 94. The depth from front to back varies between 1″ and $1\frac{1}{2}''$, and extra members are inserted to give the requisite strength, the whole being covered both sides with plywood suitably lightened.

The main landing skid is usually attached at these points.

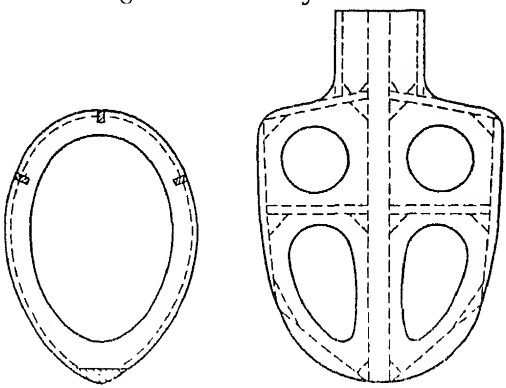


FIG. 94.—Fuselage Frames.

The rear bulkheads supporting the tail unit are stiffened up somewhat, and generally extend into the fin and fixed tail plane, if any, for general robustness.

The plywood covering of birch 3, 4 or 5-ply, is laid on transversely in strips equal to the main bulkhead spacing, and of length varying in accordance with the curvature of the body along the main axis. Difficulty is experienced in bending the ply in two perpendicular directions, so that, unless the fore and aft curvature is very slight, only short lengths of ply can be used with success. It should be noted that the main bulkhead spacing should bear some relation to the amount of curvature of the fuselage.

One method of overcoming this difficulty, and at the same time keeping a relatively cheap construction and fairly efficient shape, is to give the fuselage a straight taper from the pilot's seat to the stern, shown in Fig. 95.

horizontal struts, spaced at between 1 and 2 ft. centres, dividing the length into bays.

Diagonal bracing usually takes the form of struts, forming

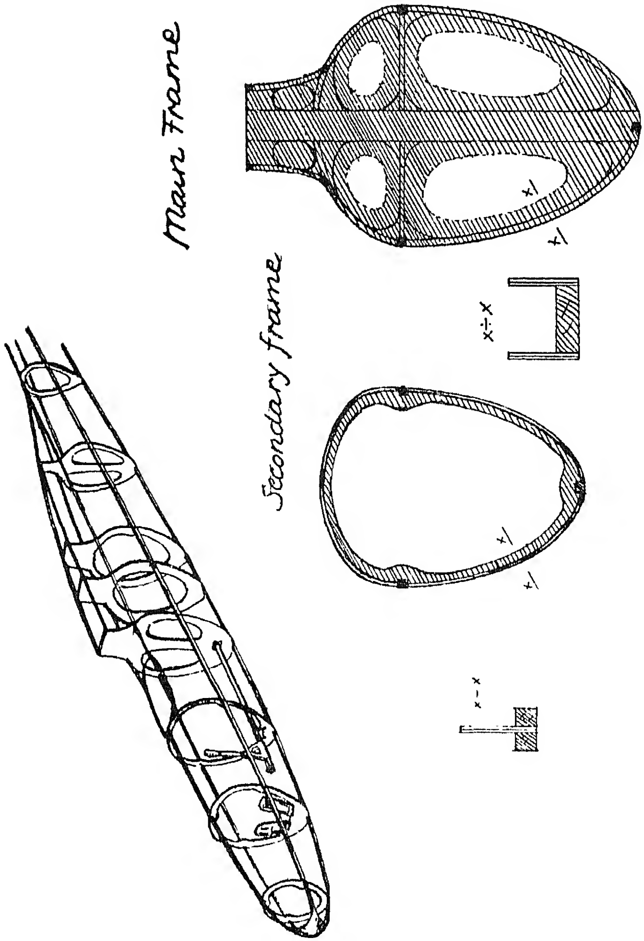


FIG. 97.—Fuselage Constructional Details.

the whole into an "N" girder, but, in some instances, cross bracing is effected by means of thin strips of spruce or other suitable timber.

The bulkheads to which the main planes are attached

An alternative method is to lay on the strips longitudinally, keeping the width to about 6″, but this entails considerably more work and is seldom employed.

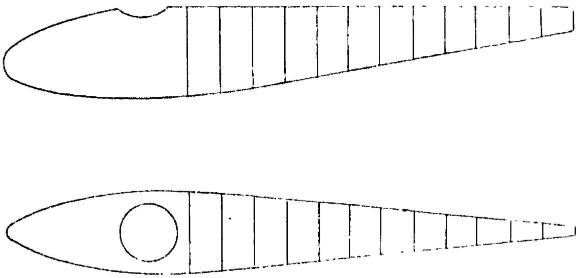


FIG. 95. Fuselage Shape.

The front portion may be built up with either lateral or longitudinal strips or a combination of both.

Figure 96 represents the front of a fuselage with a considerable curve on the top but with a fairly flat under-side. Longitudinal strips are used to obtain the curved top, while cross strips are employed for the base.

All plywood joints should be well "feathered" and glued so as to form a good splice, the face being from ½″ to 1″ in length.

The actual nose piece may be either of beaten thin sheet metal, aluminium being very suitable, or built up of a large number of small pieces of plywood on the principle of a football casing.

Braced Strut, or Girder Type, Fuselage

Fuselages built on this principle are cheaper to produce and more simple to repair than the monocoque type, besides which they have the advantage of lightness, but are not generally so efficient aerodynamically.

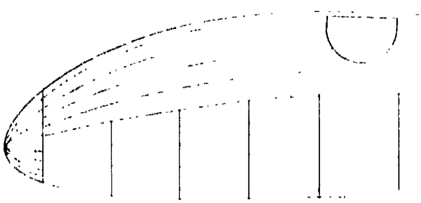


FIG. 96.
Sailplane Nose—Monocoque Construction.

They may contain four or more longerons, forming a square or hexagon in cross section (see Fig. 16), and have vertical and

horizontal struts, spaced at between 1 and 2 ft. centres, dividing the length into bays.

Diagonal bracing usually takes the form of struts, forming

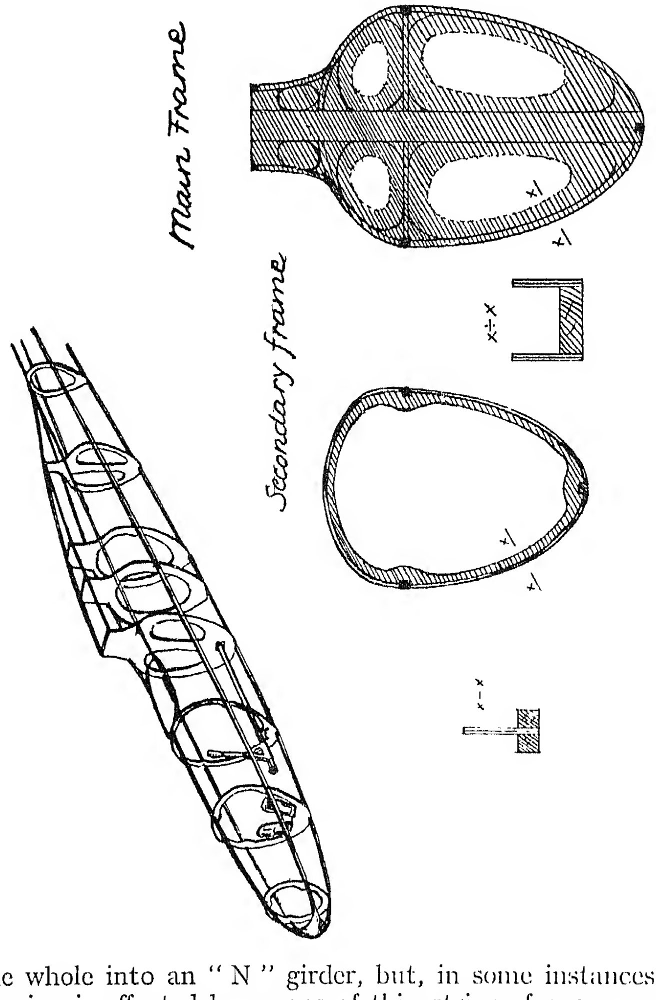


Fig. 97.—Fuselage Constructional Details.

the whole into an " N " girder, but, in some instances, cross bracing is effected by means of thin strips of spruce or other suitable timber.

The bulkheads to which the main planes are attached

generally follow, more or less, the method as described for monocoque fuselages.

Covering may be made with either fabric or plywood, or both.

A good harness, preferably of webbing, should be firmly attached to some secure member in the bulkhead behind the pilot. A harness for holding the pilot firmly to the seat is far superior to a belt round the pilot's waist, as during cloud flying or flight in gusty winds the pilot is often lifted from his seat.

Skids

There is usually one main skid for landing purposes, and a small tail skid to keep the rear of the fuselage and tail unit clear of the ground.

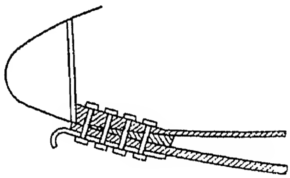


FIG. 98.
Skid Attachment at Front.

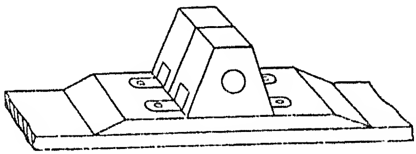


FIG. 99.
Skid Shock-absorbing Joint.

Main skids are built of ash or hickory, and may be from 3 to 4 in. in width by about $\frac{5}{8}''$ deep. They should be steamed to shape before fitting. Attachment is made to the fuselage by a rigid joint at the nose, one or two flexible joints at the main fuselage bulkheads, and a sliding joint at the rear.

The nose joint is generally made by a number of small bolts to the fuselage, which is suitably strengthened at this point, and may incorporate the main launching hook (Fig. 98).

It is usual practice for landing shocks to be taken at the main fuselage wing bulkheads by a pair of rubber compression buffers at each point. These rubber buffers are used in pairs as a safety measure in the case of one breaking, and are fixed to the skid by simple band fittings running through slots in the rubber, the skid being reinforced at this point (Fig. 99).

The corresponding fittings on the fuselage include two lugs projecting downwards and spaced the width of the pair of blocks apart. A small bolt about $\frac{1}{4}''$ diameter, supported by

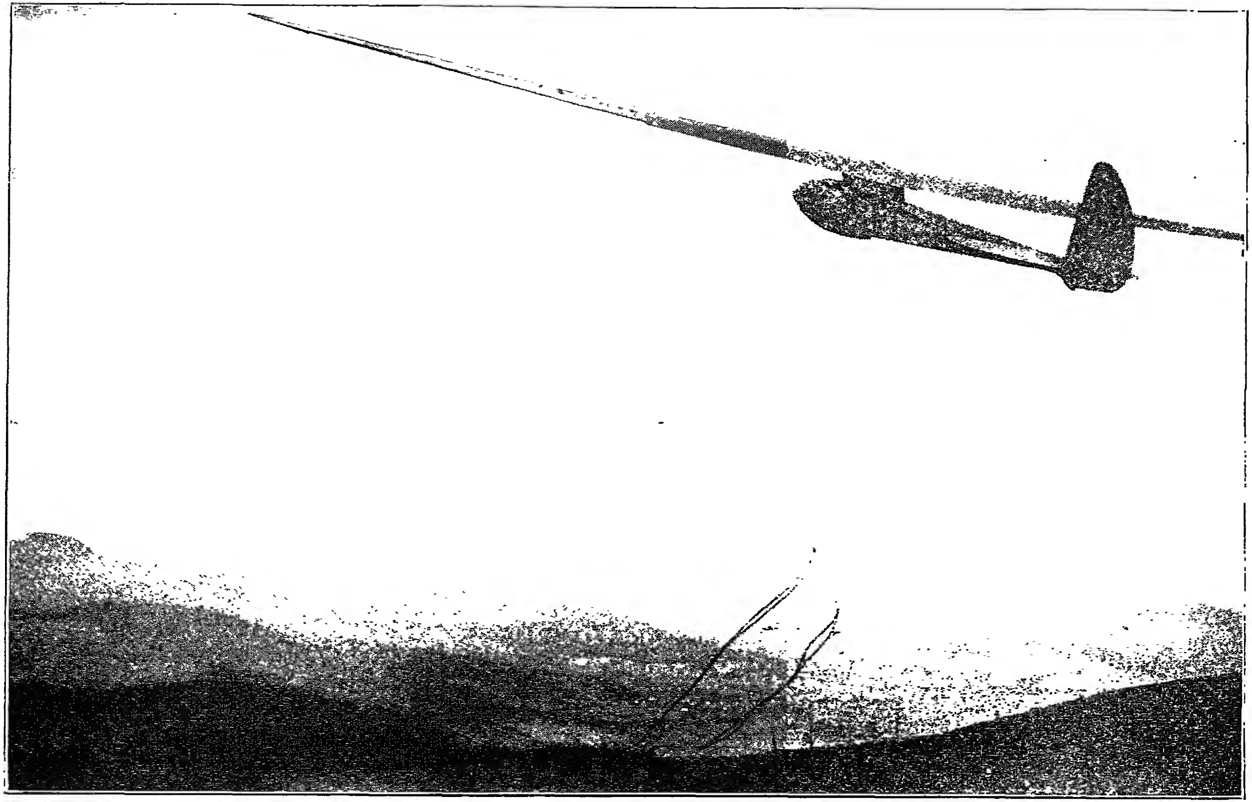


Fig. 100.—The Start of a Sailing Flight.

[To face page 140.

the lugs, runs through holes in the rubber blocks. These holes are about 1″ in diameter and the connecting bolt is situated at the top of these holes when in the normal position, thus allowing about $\frac{3}{4}''$ play both vertically and fore and aft.

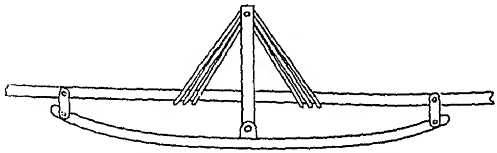


FIG. 101.—Skid Shock-absorber on "Meiningen."

The actual shape of the rubber buffers may be varied to suit the conditions as required. It is usual to cover in the sides of skids with leather or American cloth to minimise air resistance.

Another method of shock absorption is by means of rubber in tension, in which the skid is connected by vertical links to a cross horizontal member inside the fuselage. Shock absorber elastic is bound round this member and a fixed longitudinal member or other attachment below (see Fig. 101).

Sideways movement is often prevented by means of shackle plates fixed to the rear end of the skid, as shown in the figure. Coiled springs have been used in conjunction with landing skids, but are not very satisfactory as the energy is stored up in the springs and returned, thus causing the machine to bounce. A variation of this principle is obtained by using a number of single coil steel wire springs or rings connected together at the top, where the joint is made to the fuselage, and spaced out along the width of the skid at the base (Fig. 102).

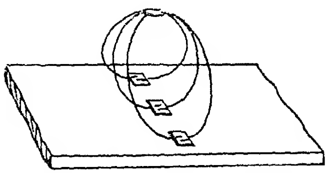


FIG. 102.—Steel Ring Skid Springing Device.

Machines have been built with no shock absorbing device at all, this being quite usual on elementary training machines, but with sailplanes of large cantilever span a heavy landing is liable to cause considerable damage and might easily result in the wings being sheared right off.

Tail Skids.—These nearly always take the form of a solid block attached either directly to the under-side of the fuselage, or, when the skid is deep, the block is supported by an extension

of the stern bulkhead and covered in with an outer covering of plywood.

In order to keep the tail plane clear of the ground, the tail skid is sometimes as much as 1 ft. in depth.

A hole is generally drilled through the tail skid for the holding back rope or steel cable, and this is often left in permanently.

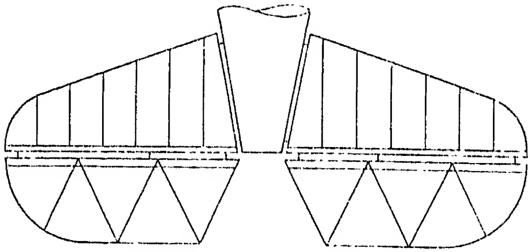


FIG. 103.—Fixed Tail Plane and Split Elevators.

The Tail Unit, or Empennage

The tail unit consists of the elevators, tail plane, if any, together with the rudder and fin.

A fairly high aspect ratio is desirable, for aerodynamic efficiency, in all control surfaces, but, on the other hand, the weight of each control is approximately in proportion to its length or span. Apart from this, the tail plane of a sailplane is limited in length by the height and span of the main plane, as it is important that the tip of the tail plane should be clear of the ground when the machine is resting on one wing-tip. For this reason it is usual to place the tail plane on top of the fuselage or as near to the top as is reasonably practicable.

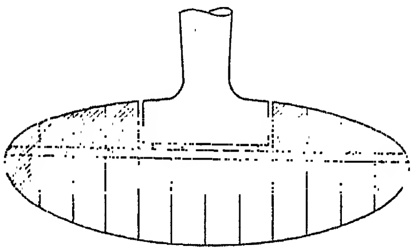


FIG. 104.—Small Built-in Tail and Single Balanced Elevator.

The tail plane may be either a single unit attached directly above the fuselage, or may be divided into two halves so as to fix on to the sides (Fig. 103). In the latter case it is usual to support the tail by small struts to the bottom of the fuselage.

This method, although cheap, does not permit of a very clean design, and a better way is to build a small fixed tail plane integral with the fuselage, as Fig. 104. In this case the rear fuselage bulkheads continue into the tail and the whole

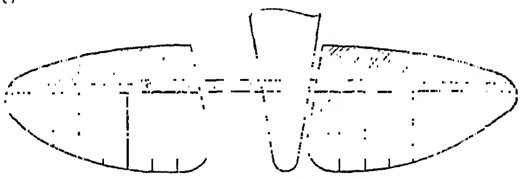


FIG. 105.—Pendulum Type Elevators.

is covered with plywood to form a rigid support for the elevator. The elevator may be in either one or two parts.

In order to avoid the gaps formed by the joint of the elevator and tail plane, and also to simplify construction, tail planes are often done away with altogether, balanced elevators only being used in such cases.

These elevators, when there is no fixed tail surface, are generally made to slide on to a strong tubular member fixed into the fuselage, but mounted in bearings so that rotation is possible (Fig. 105). One or two vertical bolts or pins are used to secure the connection. If the tubular member is fitted with king-posts inside the fuselages it becomes unnecessary to disconnect the control cables for dismantling, a factor of some importance.

When fins are used these may be incorporated in the fuselage structure, in a similar way to the built-in tail plane described above.

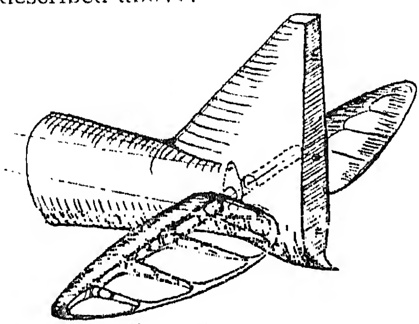


FIG. 106.
Empennage—" Professor " Type.

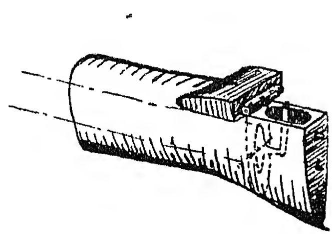


FIG. 107.
Empennage—" Darmstadt " Type.

The advantage of a fixed fin is that a greater length is provided for rudder attachment than is available if the fuselage alone is used for this purpose.

Rudders are always balanced, if no fin is used, and partly so if the rudder rises above the top of the fin. This is done not so much to ease the load on the pilot's rudder control pedals, but in order to utilise the thickest part of the rudder for the main spar position.

The construction of elevators and rudders follows generally along the lines indicated for main planes and ailerons, to which reference should be made. Plywood comes into considerable use over the leading edges, for torque resistance and for robustness at the tips and trailing edge, and for all joints.

Spars are of box section, or metal tubes, or of " I " section where a torsion resisting leading edge is employed.

Where fixed tail planes or vertical fins are used, ribs may, with advantage, be triangulated for strength, as explained in connection with ailerons, but with balanced units it is better to carry the ribs straight back from leading edge to trailing edge.

Diagonals may still, however, be inserted between these to make the unit quite rigid.

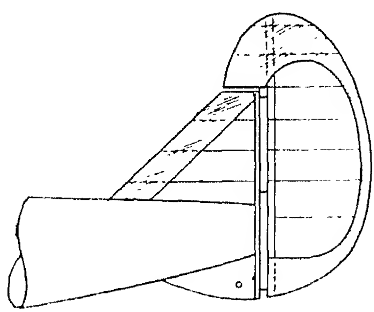


FIG. 108.
Fin and Rudder Construction.

CHAPTER XII

Fittings and Control System

Fittings, General—Spar/Fuselage Fittings—Leading Edge/Fuselage Attachment Fitting—Main Plane Junction Fitting—"Professor" and "Darmstadt" Types—Attachment Bolts and Pins—Strut-End Fittings—Strut/Spar Fittings—Strut/Fuselage Fittings—Skid Attachment and Launching-Hook Fittings—Tail Unit Fittings—King-Posts—Control Cable Connection—Control System, General—Control Column—Rudder Control.

General

The fittings on a sailplane, apart from control fittings, are few in number, but are of great importance as their duties are seldom shared as often happens in power machines or, in other words, if such fittings fail in the air, there is no alternative route for the loads to be transmitted through, and consequently complete structural failure is almost bound to follow. For this reason all fittings should be very carefully designed and a good factor of safety allowed.

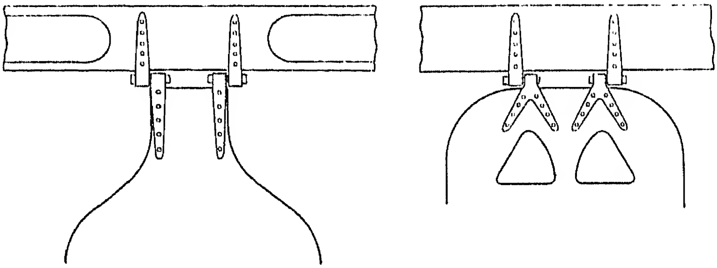
The main fittings consist of those connecting the main plane to the fuselage and the various portions of the main plane together (unless the wing happens to be in one piece), those joining the main lift struts to wings and body; the skid fitting; tail fittings and the normal control surface hinge fittings.

All fittings should be designed for rapidity of assembly and dismantling, so that the sailplane may be taken to pieces and erected in the shortest possible time. This factor is of such importance that it should be very fully considered before making the choice of the type of fitting to be adopted for any particular joint.

Where the loads are likely to be large, such as in the transmission of the main lift forces, or applied suddenly, as in the case of a heavy landing, it is as well to extend the metal fitting over a large area of the timber to give an even distribution of

the forces and thus avoid shear or impact fracture. For this reason several small bolts are much preferable to a single large bolt.

Most fittings can be very simply made from bent up sheets of steel, and need seldom be of thicker gauge than 16 S.W.G.,



FIGS. 109–110.—Main Plane/Fuselage Attachment Fittings.

and as thicknesses less than 20 gauge are seldom called for, the complete set of fittings for a machine can generally be made from steel of, say, 16, 18, and 20 S.W.G.

Duralumin is sometimes used, but is not favoured as much as mild steel.

Spar/Fuselage Fittings

Figs. 109 and 110 show typical joints for the main spar and fuselage; the former being suitable where a "neck" separates the wing from the body and the latter being for use when the wing connects directly to the fuselage.

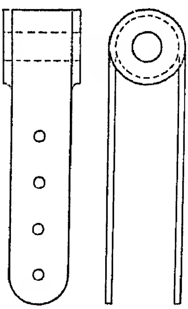


FIG. 111.
Main Plane Spar/
Fuselage Fitting.

These fittings are simple to make and consist of steel plate bent in the shape of a long "U"; the actual bearing being generally strengthened up with a solid cylindrical piece drilled out to the required diameter for the fixing pin.

The cylindrical part may be held in position by means of small flanges turned on the ends (see Fig. 111), or may be brazed into position.

The actual connection may be by solid pins at each joint, Fig. 112 (*a*), by hollow pins connected by one long bolt as at (*b*),

or by a single pin through both fittings (*c*). In the last case it is usual to reduce the diameter over the central portion, for lightness, and a small handle may be included to assist in getting the pin into position.

The fittings are held to the spars and fuselage bulkheads by a number of small bolts.

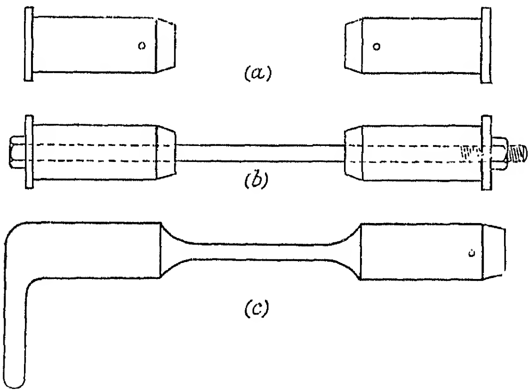


FIG. 112.—Connecting Pin Types.

An alternative method of attachment to the above employs somewhat similar fittings on the fuselage, but on the spar each fitting is split into separate plates, forming lugs in front and behind, the whole then being held together by a bolt or pin from front to back.

Leading Edge/Fuselage Attachment

This fitting generally resembles the main spar fittings and attaches to a bulkhead in the fuselage.

When the leading edge is ply covered, for taking torsional loads, it is necessary to transfer these loads to the fuselage, and this is best done by means of a rigid attachment fitting, especially is this the case in a single spar machine.

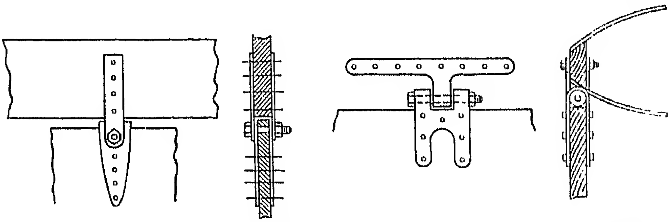
It is possible to increase the strength of the main spar for this purpose, but this is very uneconomical, apart from which the loading in the torsion tube has to be transferred to the spar by suitably placed members.

It is usual to strengthen the leading edge at the centre of the wing and at all wing joints, so that the down load in the leading

edge member, caused by the torsion, can be suitably transmitted by means of fittings. (This has been explained in Part I.)

Both parts of the fittings are bent up " U " sections with strengthening ferrules. The fitting on the leading edge member may have lugs extending outwards so as to take a larger number of bolts and thus provide a firmer anchorage. (Figs. 113 and 114.)

One bolt or pin can be employed for fastening the joint.



FIGS. 113-114.—Leading Edge to Fuselage Attachment Fittings.

Main Plane Junction Fitting

As in the method of fuselage attachment, so also here, the question of ease and rapidity of assembly is of primary importance, and fittings including several fastening bolts or pins should be avoided. Tapered pins are much simpler to use than bolts and also allow for wear, in that, if the holes become slightly enlarged, a tight fit is still possible.

There are two main types of fittings in use for main spar joints, in one of which flat plates are secured to the front and back faces of the spars, so as to form extending lugs through which the locking bolts are placed, and in the other method the spar flanges are capped and cupped to fit one into the other, the bolts or pins being inserted vertically from above and below the wing.

" Professor " Type Joints

The flat plate method of spar joint is shown in Fig. 115, and consists of plates cut in the shape of an " H," so that the legs of the " H " run along the flanges of the spar, to which they are bolted, and small flanges are often turned up along the edges of the legs to give stiffness to the whole. The plates on one spar of the joint are let in flush with the webs, or

sides, whilst on the other spar they are raised so as to fit over the former pair.

The actual lugs are generally strengthened up for bearing surface by means of brazed-on washers and the holes are drilled to take a tapered pin fitted with a butterfly nut.

The spars should make close butt joints, but a slight cut away portion below the lower bolt is advantageous in assembling the wings, as the wing-tip may be left resting on the ground, or held just clear, while the bottom bolt is placed in position, after which the tip can be lifted as high as it will go and the top bolt slipped into position. In this way the fittings and spars stand little chance of being strained.

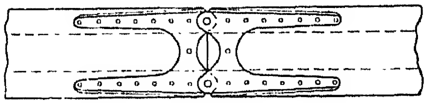


FIG. 115.—Main Plane Spar Joint. "Professor" Type.

This makes an exceedingly neat fitting, and is easy to manufacture, but it suffers from two disadvantages.

In the first place the full depth of spar is not made use of for transmitting the bending load—the resisting couple being the product of the strength of the bolt and the distance between the bolts—so that larger bolts than would otherwise be necessary have to be employed, and, secondly, a gap has to be left between the two portions of wing in order that the pin may be inserted and withdrawn. This can be covered with a sliding strip of celluloid, or plywood, thus making an aerodynamically clean joint, and, as this can be fitted in a few seconds, this objection is of little account.

"Darmstadt" Wing Joint

This consists essentially of male and female welded-up box fittings on the ends of the spar flanges, each flange having a separate fitting. On one side the fitting forms a cap to the projecting spar flanges, the fitting being let in flush, whilst the sockets on the other side are fitted externally. Extra strips are placed on both sides of the spar in a vertical position, as shown in the Fig. on page 90, Chapter VII, to hold the whole firmly together.

Fixing can be done by one bolt or pin passing through both flanges or, preferably, by separate bolts for each flange and, in order to accomplish this, the nuts are welded to the inside

of the socket fitting. Still another alternative is to employ separate bolts which lock one into the other, a method specially suitable when the top and bottom flanges are fairly close together.

A modification of this type of joint employs a "U" fitting for the male end, very similar to the attachment fitting of the fuselage, shown in Fig. 111, and should be bushed for preference.

Attachment Bolts or Pins

Plain bolts are seldom used for this purpose, owing to the tight fit necessary. The plain tapered pin, the amount of taper being quite small, is largely used and is fitted with a wing nut. Locking is done by means of a piece of soft wire placed through a hole in the wing nut and bound, either to another wing nut, or to some fixed part of the machine.

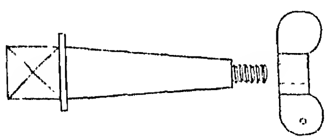


FIG. 116.
Tapered Attachment Pin.

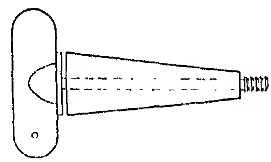


FIG. 117.
Tapered Sleeve Attachment Pin.

Fig. 117 shows a very ingenious tapered bolt which is often used in conjunction with the "Darmstadt" type of fittings. It consists of a hollow tapering sleeve, making a sliding fit with a small diameter bolt. The bolt head is of wing shape, whilst the threaded portion has a larger diameter than the shank so that the tapered sleeve will not come apart.

A small clearance is allowed between the ends of the sleeve and the bolt.

In action the sleeve does not rotate and is not, therefore, damaged by the sharp edges of the other fittings. The tightening action of the bolt merely forces the sleeve well home. It will be noticed that the sleeve takes most of the shearing load, due to the transmission of the bending moment at the joint, whilst the bolt acts as a means of getting the sleeve into position and then holds it there.

All bolts and pins should, wherever possible, be placed with the bolt head uppermost or to the front, so that in the event of a nut working loose, and coming apart, the bolt will remain in position.

Strut End Fitting

Up to the present time most main plane lift struts have been built in wood and encased in a plywood fairing. If, as is often the case, the main member of the strut is placed laterally in section (Fig. 118 (*a*)), so as to use the plywood casing

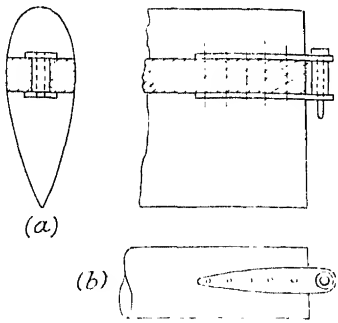


Fig. 118.
Strut End Fittings.

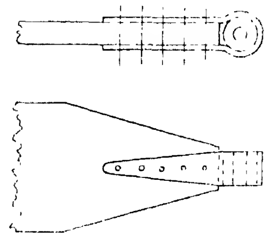


Fig. 119.
Strut End Fitting.

for strength along the longitudinal axis, then plates may be bolted to both sides of the main member and the lugs drilled to a larger diameter than is required for the attachment pin, so as to accommodate a sleeve or bush (Fig. 118 (*b*)). This bush may be held in position by welding, or any other suitable means.

For struts of solid section, and built-up struts, which include a main member of thicker section longitudinally than that illustrated at Fig. 118 (*a*), a single plate bent to fit both faces (Fig. 119), makes a simple fitting. It should be secured to the strut member with several small bolts and may be bushed if desired. Instead of the flanges of the fitting bolting outside the strut, they may be brought together and inserted in a saw-cut down the centre of the strut, the whole being bolted together as before.

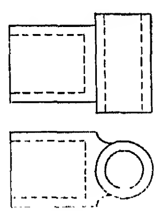


Fig. 120.
Metal Strut
End Fitting.

Metal tubular struts are generally fitted with

machine-turned, end-capping pieces which may fit inside, or outside, the tube and fix with pins or brazing.

Sometimes metal tubes are trapped down at the ends, in which case similar fittings to those already described can be made to serve. This applies also for tubes of oval or stream-line section.

Strut/Spar Fittings

These are usually simple plate fittings bolted to the spar at the same angle as the strut takes when in position. A small flange turned up along one side of each plate lends the necessary stiffness and prevents bending of the fitting during assembly.

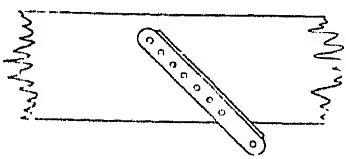


FIG. 121.—Spar/Strut Fitting.

This fitting is sometimes combined with the one connecting the outer part of the wing to the central portion, which makes possible a reduction in the number of securing bolts, in the number of fittings and also of weight.

Strut/Fuselage Fittings

The main lift struts should, for preference, be attached to the main bulkheads in the fuselage, in which case plate fittings closely resembling those described for the spar-strut joint are most suitable. It is, however, sometimes necessary to make attachment to the bottom longerons, or to the keel in certain cases, and these may then take the shape of " U " pieces with extending lugs to fit round the strut end (Fig. 122).

In bolting the fitting to the fuselage member, care should be taken to arrange for the bolt heads or nuts to be placed close up to the lugs to prevent the lugs from pulling when subjected to tension loads, or, alternatively, an extra

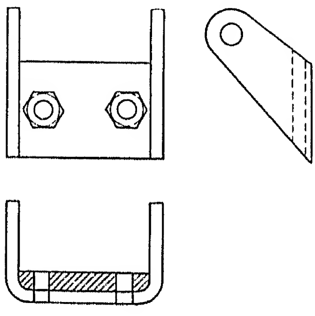


FIG. 122.
Strut/Fuselage Fitting.

plate with rounded edges at the base may be inserted as shown in the diagram.

When attachments are made to such members it is essential that the load should be suitably transmitted to the main bulkheads.

Skid Attachment and Launching Hook Fitting

The launching hook consists sometimes of a simple stout hook fitted with a large collar, to distribute the pressure over a wide area, and a shank to pass through holes drilled in the skid and keel, and is fixed by a nut and washer.

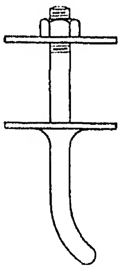


FIG. 123.
Launching Hook.

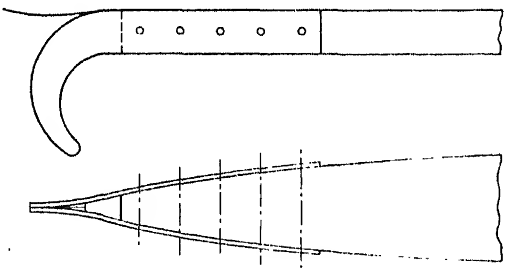


FIG. 124.
Launching Hook.

As explained in the paragraph dealing with skids (page 140), the nose of the fuselage is generally strengthened up at this point.

An alternative method is one in which the hook is attached strongly to, or passes through, a flat plate of steel, which, in turn, is secured to the under-side of the skid and fuselage by a number of small bolts, while another type of hook fitting is turned up from a sheet of metal to fit over the front of the skid with the ends coming together to form one (over the hook portion), as shown in Fig. 124.

Tail Unit Fittings

Fixed tail surfaces are seldom used unless they are built-in with the fuselage. In other cases they are generally split into two halves and attached on each side of the body by simple forked eye-bolts similar to the hinge fittings.

Such tail planes are supported by wires above and below, or, preferably, by struts only, which connect the under-side of the tail plane spar from a position, approximately one-third to one-half the span from the root, to a point near the base of the fuselage, generally at the stern post. The fittings used for both wires and struts consist of plain strips of steel bent to the angle of the wire or strut with the fuselage, and are suitably bolted into position.

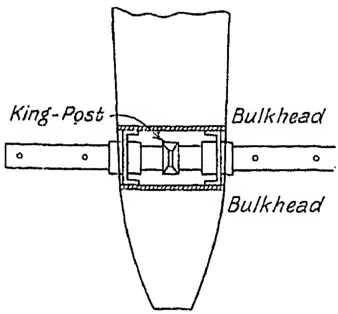


FIG. 125.
Elevator Attachment Fitting.

When there is no fixed tail plane the elevator may be either in one or two parts. If in one, it is attached to the stern with simple hinge fittings, but, when the elevator is halved, the support fitting generally follows the rather ingenious method first evolved for the " Professor " type of empennage. This type has the great advantage that no controls need be undone during dismantling of the machine, so that adjustment of the cables is rendered unnecessary.

A fairly large diameter tube is fixed into the rear end of the fuselage, so that it protrudes on each side by about 8 to 15 in. (Fig. 125).

The tube is rotatable in bearings, which are fixed to supporting channel pieces, which, in turn, are attached to bulkheads in the fuselage.

A corresponding tube in the elevator, which may form the main spar, slides over the supporting tube and is fixed in position by either one or two bolts.

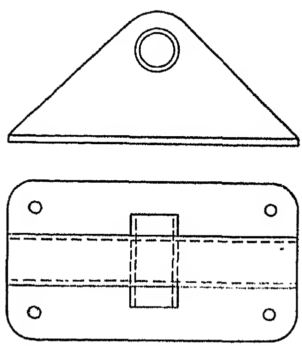


FIG. 127.—Rudder Hinge.

The tube may be bushed to receive these bolts, both for ease of assembly and also to provide a larger bearing surface between the bolt and tube, and the main tube may be drilled or otherwise suitably cut away for lightness.

King-posts are fixed at the

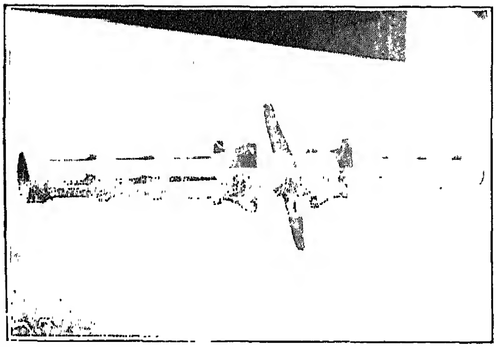


FIG. 126.—Elevator Hinge Tube in "Professor."

[*To face page* 154

centre of the tubular support to which the control cables are attached. Rudders, ailerons, and also elevators used in conjunction with fixed tail planes, are seldom hinged otherwise than with normal forked eye-bolts. They should either include a collar of large diameter, or should be fitted with a large washer under the head, and another washer under the nut, so as to spread the load over a large area and avoid cutting into the spars.

Hinge pins should be a good fit and lock with safety pins, split pins or locking wire. In some instances these fittings have been made from welded-up sheet, in the manner shown

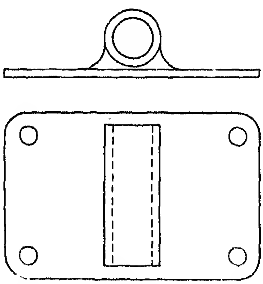


Fig. 128.—Rudder Hinge.

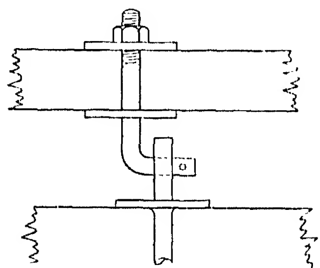


Fig. 129.—"L"-type Hinge.

illustrated in Fig. 127, but this seems unduly elaborate, and a simpler method is shown in Fig. 128, in which a piece of tubing is brazed to a flat plate. This is very simple, but is somewhat unreliable, as the strength depends solely on the brazed joint.

In another type, " L " shaped bolts are used in conjunction with eye-bolts, but this is not strongly recommended.

The use of any fittings that are held in position with wood screws is unsatisfactory, owing to their liability to work loose, and the rotting of timber which so often sets in after some time, especially when exposed to the weather.

King-Posts

These are sometimes made of multi-ply or spruce faced with plywood, and are glued and, sometimes, screwed to the spars, though very often they are bent up from sheet metal, either steel or duralumin, whilst in a few cases oval tubing has been utilized.

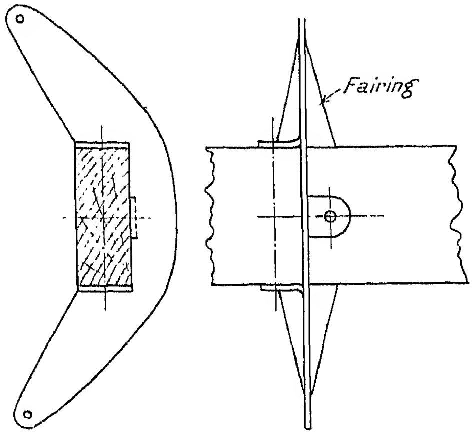


FIG. 130.—Aileron King-post.

A simple plate fitting is shown in Fig. 130, in which lugs have been turned out above and below and on the inside of the spar, these being fixed by small bolts. The actual king-posts are strengthened up with wooden fairing pieces, both to reduce drag and to prevent buckling in a sideways direction.

Box king-posts, either welded or riveted, can be employed, but are not usual in sailplane construction. Some machines have king-posts made in the form of a circular arc with a groove cut down the outside circular edge. The cable is attached at the base of the post and runs along the groove, so that the lever arm remains of constant length at all angles of the control unit, instead of becoming less at higher angles, as is the case with some fittings. This also enables the cable to pass into the main plane at one fixed point for all aileron angles. King-posts have been made of a single piece of oval tubing bolted at the centre to the spar and strengthened at the ends to receive the cable pin, but this is not wholly satisfactory.

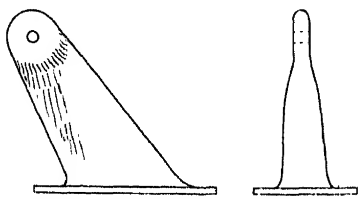


FIG. 131.—Welded Box King-post.

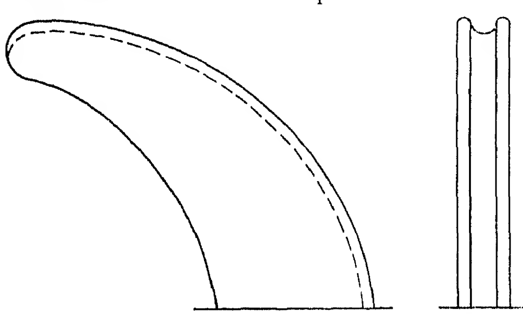


FIG. 132.—Constant Leverage Control Lever.

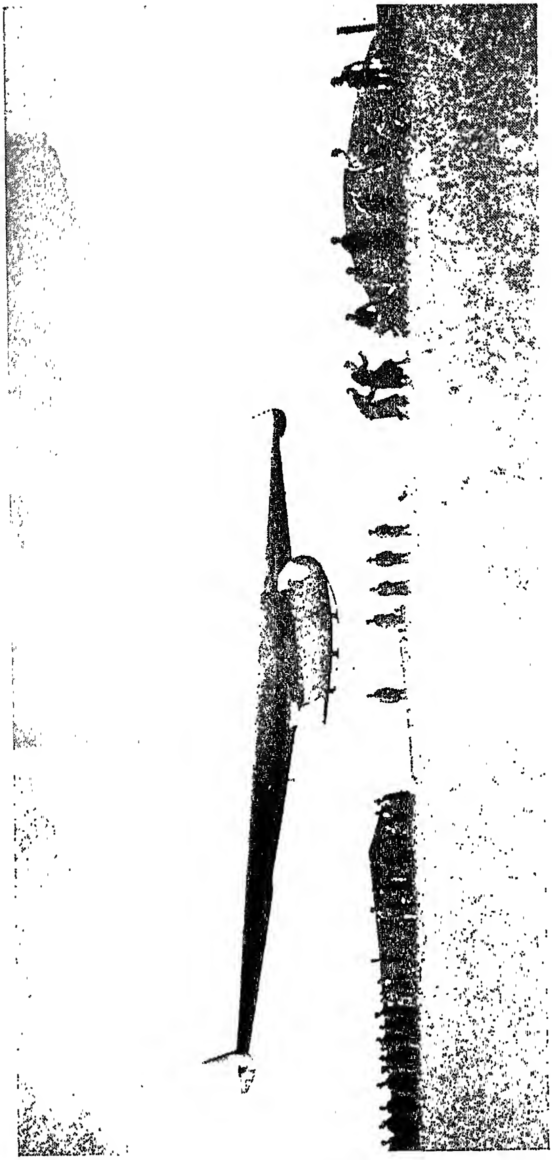


FIG. 133.—The Two-seater Tailless Sailplane being Launched.

[*To face page* 156.

Control Cable Connection

Where wings and other parts have to be dismantled often, it is inconvenient to have to undo turnbuckles to release the cables, apart from which careful adjustment is necessary again at each assembly. A simple fitting to overcome this consists of "T" piece and stirrup attachments fitted to the ends of the cable, the stirrup being bent up from a strip of steel and provided with a slot (Fig. 134).

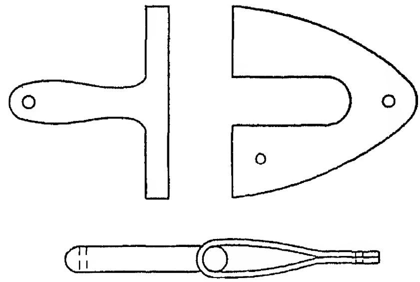


FIG. 134.—Control Cable Connection.

In assembling, the head of the "T" piece is placed along the slot of the stirrup, with the tail portion perpendicular to the stirrup, and rotated through a right angle to the position shown. To prevent movement after fitting, a small piece of locking wire is then inserted through the small hole, shown in the stirrup, and locked.

Control System, General

The controls of a sailplane resemble closely those of a normal power aeroplane, the principles, of course, being exactly the same.

They should, however, be designed for lightness consistent with adequate strength, due allowance being made for wear and tear. For example, it will be found that 5 cwt. cable will be sufficient to transmit practically all control loads necessary with a sailplane, but, owing to possible fraying and wear, controls are generally made with 10 cwt. or even 15 cwt. cable.

The cockpits of sailplanes are more confined than those of aeroplanes, and the control system has to be modified to suit these conditions.

Lubrication of moving parts should be provided for, and pulley guards should be fitted wherever possible to prevent any slipping off of the cables. Inspection panels, consisting of small celluloid plates, should be fitted in the vicinity of all control pulleys in the wings, to enable a quick visual check to be made after erection, or before a flight.

Control Column (Ailerons and Elevators)

The simplest form of this control consists of a vertical column, or joystick, which pivots about a fulcrum situated about one-sixth to one-quarter of its length from the lower end. The cable is attached to the base, passing forward and over a pulley and thence back to the elevator king-post, round another pulley at the stern and forward again to the control stick. It will be noticed that it is necessary to cross the cable to obtain the desired effect on the elevators. The fulcrum pin, referred to above, is housed in a support stirrup attached

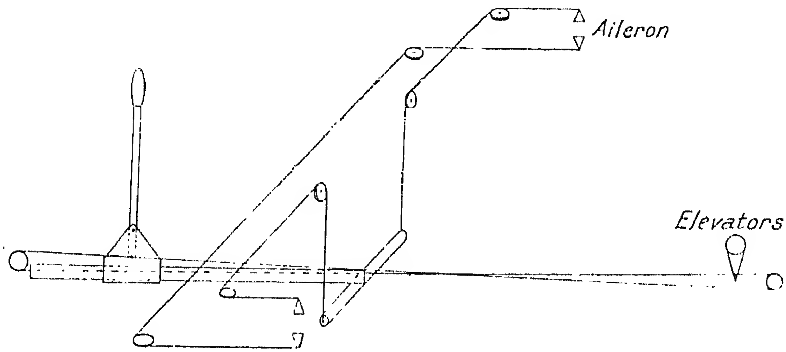


FIG. 135.—Simple Control System.

to a torque tube which is suitably fixed to the floor of the cockpit, but free to rotate. At the rear end of the torque tube a rocking-shaft is rigidly attached, so that sideways movement of the control column deflects one end of the shaft, and raises the other, in a lateral plane. Cables join the rocking shaft to the ailerons, so that when one aileron moves down the other moves up, and a check cable joins the ailerons across to complete the circuit.

There are very many variations of control arrangement, although practically all are based on the same principle. An alternative for elevator control is to connect the base of the column to a shaft running back to a vertical lever, pivoted at the centre, with the cables from the elevators connected to each end (Fig. 136).

In place of the rocking shaft for the ailerons there may be a single vertical king-post attached to the torque-tube, to the

extremity of which both cables join; or again, a vertical king-post may be fixed to a horizontal sleeve supporting the joy-stick at the pivot (see Fig. 136). This may be so arranged that fore and aft movement of the stick does not move the sleeve, but it is rotated by sideways movement, thus giving the king-post and cables a lateral displacement.

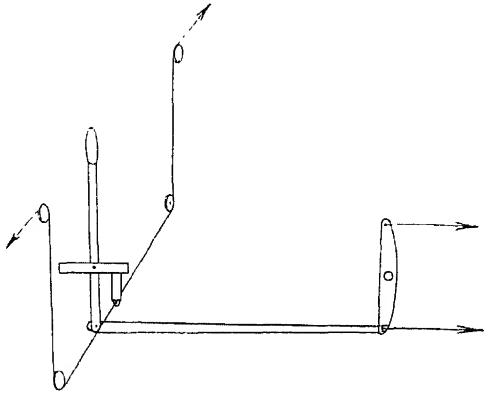


FIG. 136.—Control System.

Wheel control can be substituted advantageously where the cockpit is narrow. In such cases the elevator control remains as before, but, instead of the column moving sideways, a wheel with pulley attached is substituted for this purpose. A cable or chain is connected to the pulley at the top, and passes down both sides, so that rotation of the wheel tends to shorten one side and lengthen the other. The cable may then pass over other pulleys and out to the wings (Fig. 137), or the cable or chain may be made endless by passing round a second pulley or wheel at the base. Lugs, fixed on the pulley, connect to a trunnion, forming a joint with a torque tube (Fig. 138). The remainder is similar to the other methods already described. Where a cable is used it is pinned, or otherwise attached, to the pulley at the extreme top to prevent slipping.

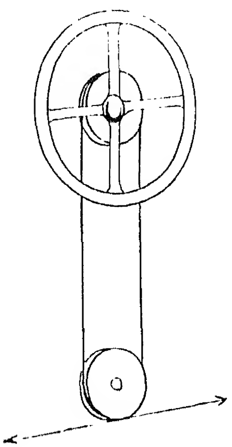


FIG. 137.
Wheel Control.

Easy detachment of the aileron controls, during dismantling, can be arranged for by the employment of a vertical tube or rod, connecting a lever arm on the torque tube to the corresponding arm of a cranked lever attached to the aileron cables. On

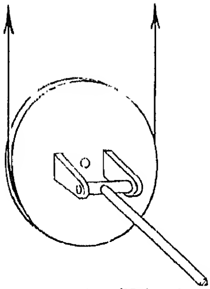


Fig. 138.—Wheel Control Details.

erection the vertical rod is passed up through an aperture in the lower side of the centre section plane and is attached to the crank from above. This is effected by means of a sliding or detachable panel in the top of the wing.

Aileron controls should be on the differential system for preference. That is to say, the control arrangement should be so adjusted that the down-going aileron has very little movement compared with the up-going aileron, with the result that little extra drag is caused on the outside wing. This is important for two reasons, firstly because height will not be lost on a turn due to the upsetting of the air flow, which normally takes place with an aileron fully depressed, especially on thick wing sections, and secondly, the tendency to stall and spin is largely obviated.

Stretching of the cable, under load, can be reduced to a minimum by loading before use. A weight, equal to the maximum control load designed for, is left suspended from the cable for some hours, and in this way the initial stretch is taken out.

Rudder Control

This control, in its simplest form, consists of a rudder bar pivoted at the centre, with cables attached to the ends and to the rudder king-posts.

The rudder bar may be of solid ash, or of steel, or duralumin, tubes. Flexible steel cables fitted with adjustable turnbuckles should be used and may be connected either inside or outside the pilot's feet. It is usual to keep the cables parallel for a short distance, after which they pass round pulleys or fairleads, and thence to the rudder king-posts. Piano wire is

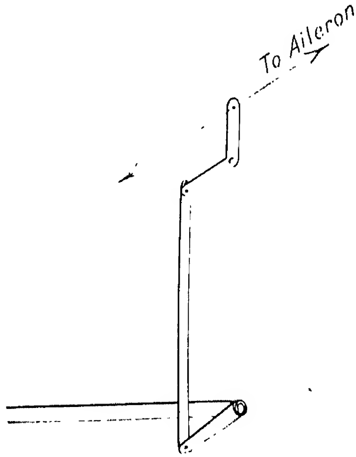


Fig. 139. Aileron Control Mechanism for Quick Detachment.

sometimes used, but is not recommended owing to its liability to snap.

Owing to the small width of fuselage near the nose where the rudder bar is situated, pedals are often substituted. These generally take more or less the shape of a foot, and are hinged at the base, with the cables connected about 4″ up from the

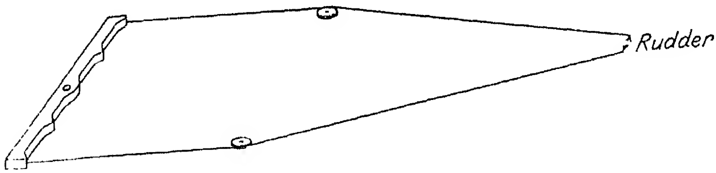


FIG. 140.—Rudder Control.

hinge, the distance depending on the amount of leverage required for the length of king-post chosen for the rudder.

A check cable is recommended, connecting both pedals and passing over a pulley some distance forward or behind the rudder pedals to prevent excessive loads being exerted on the rudder king-posts, although this is not essential.

A modification of the pedal system, and one that is very suitable for sailplane purposes and at the same time easily made, is one in which two tubes or bars of fairly small diameter are bent to the shape of an inverted "L." The lower ends are pivoted on a pin suitably supported (see Fig. 141), while the shorter arm is used for the foot-rest. Small capping pieces should be attached on the outside ends to prevent slipping of the feet, and small lugs are formed on the vertical arms for the cable attachment.

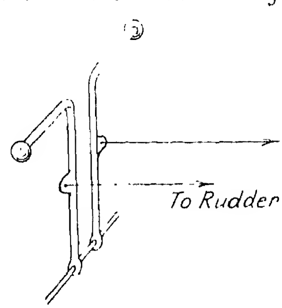


FIG. 141. Rudder Pedals.

This arrangement, and the pedal system to some extent, is capable of adjustment for pilots of different height; this being a feature difficult to obtain with the orthodox rudder bar, unless fitted with adjustable pedals.

Some sailplanes have been constructed with twin rudders, in which case it is usual for each rudder to act outwards only

M

and independently of the other. The pedals have separate action and connect only to the corresponding rudder. In this way both rudders can be actuated at once to form an air break. Light springs hold the rudders in their neutral position.

FIG. 142.—Pilot's Seat and Controls—" Fafnir."

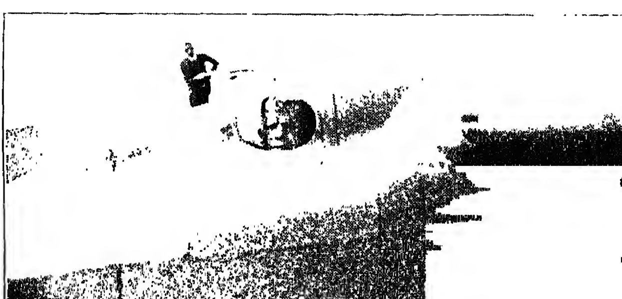


FIG. 143.—Wing Attachment and Pilot's Cockpit—" Fafnir."

[*To face page* 162.

CHAPTER XIII

Materials of Construction

Spruce—Ash—Plywood—Steel—Aluminium—Duralumin—Cement and Glue—Fabrics—Brads—Dope—Spliced Joints in Timber—Launching Elastic—Wires, Cables, etc.

Sailplanes should be constructed of nothing but the best of materials. Unlike training gliders, the advanced machines are designed for extreme lightness compatible with the necessary strength requirements of flying and handling conditions. Inferior materials cannot produce the most efficient machines and either the flying qualities or the strength must suffer.

A good sailplane has as little redundant material as a power machine, and perhaps less.

The chief material of construction, at the present time, is timber and, although attempts are being made to effect a change-over to metal, it is fairly certain that timber will at least hold its own for several years.

The main advantages gained by, and the reasons for, the use of metal for aeroplane construction are :

(*a*) Less fire risk,
(*b*) The lack of suitable timber in large quantities,
(*c*) A saving of hand-work during manufacture, and
(*d*) The possibilities of mass production, especially beneficial in time of war.

These factors are of very small importance with sailplane manufacture, apart from which the employment of timber has the following definite advantages :

(*a*) Cheapness.
(*b*) Ease of repair. Pilots and club members can effect their own repairs to a large extent, and need not be very experienced craftsmen for the job.
(*c*) Timber structures lend themselves readily to alterations and additions.

Plywood is used very largely in sailplane design. It is strong, comparatively light, easily manipulated, and does not dent as does metal sheeting.

The chief materials are silver spruce and plywood, whilst ash is employed for parts subjected to bending, rough usage or wear, such as main skids.

Spruce

Spruce is used for spars, longerons, struts and ribs, where strength and lightness are the main considerations. It should have a moisture content of between 14 and 17%, and a straightness of grain of 1 in 15, that is to say the grain should not deviate from a line parallel to the edge to a greater extent than this. It should be quite free from knots and other irregularities.

Ash

This is used for skids and other parts which are bent before use, or are subjected to bending during use, also where hard blocks are required, and for parts subjected to wear.

The moisture content should be no higher than 16%, with a straightness figure of 1 in 10.

Plywood

Plywood is employed to a large extent in the manufacture of sailplanes. It is chiefly used for leading edge covering, fuselage covering, spar webs, strut fairing, fuselage bulkheads and gussets in ribs, fuselage, etc.

It is manufactured from birch, mahogany or teak, with central cores of birch, poplar or whitewood, and is obtainable in three, four, five, or more, plies.

Alternate veneers are laid with the grain perpendicular to, or at some angle to, the adjacent layers, and are glued together with a good waterproof cement under pressure.

The cement is forced into the grain, with the result that the sheets are stronger than the timber from which they are made. Both the outside layers have the grain running parallel to the length of the board.

Joints in the veneers should not be frequent and should be well staggered.

Steel

Most sailplane fittings are made of bent-up mild steel sheeting, and are very often welded.

Steel sheet (28 ton), to specification B.E.S.A., 2.S.3, is easily worked and is suitable for welding. Steel bar for bolts rods, etc., should be to specification B.S.S. 3 S.1, of 35 to 45 tons per sq. in. maximum stress, and steel tubes chosen from those given in Appendix VII, Table 11, according to the purpose for which required.

Most steel needs heat treating, after working, to restore it to the original strength. Steel to specification T.6 and 89A. need not be normalised, but if left untreated it has only about two-thirds of its full strength.

Aluminium

There are three grades of aluminium, soft, half-hard and hard, the hard having nearly twice the strength of the soft. As aluminium is seldom used where it will be subjected to any but very light stresses the soft grade is generally used.

It is also available in bar and tube form.

Duralumin

Duralumin has been used to some extent for simple fittings. Owing to its softness in comparison with steel, and the ease with which it becomes distorted, it is not greatly favoured except for protected parts. Also it is not easily welded.

Duralumin can be obtained in sheets, bars and tubes.

Cement and Glue

Casein cement, or cold water glue, is obtained in powder form, is simple and quick in use, and is favoured for aeroplane construction.

The powder should be mixed with an equal quantity of water and well beaten up or stirred to form a homogeneous pasty fluid. It is ready for use in ten minutes after mixing, but should only be used during the day on which it is made. For this reason small quantities should be made as and when required.

The cement should be applied to both surfaces to be joined and allowed to become tacky for best results. The parts

should then be clamped together with a moderate pressure (200 lbs./sq. in.) and left for 16 hours.

When clamping, care should be taken to prevent any slipping of the parts.

The shear strength of joints should be not less than 1,100 lbs./sq. in.

Gelatine glue, or hot water glue, is applied hot, and parts are clamped together as before. Shear strength, 1,100 lbs./sq. in. Such glue should be applied in a temperature of not less than 70° F., and the parts left in the glue room for a sufficient time to prevent chilling.

Overheating and re-heating are detrimental to its strength.

Fabrics

Fabric may be of Irish linen or Egyptian cotton. There are various grades and weights, but a close mesh is desirable. The weight should not exceed 4 oz./sq. yd. Some of the lighter fabrics hold more dope and are therefore of doubtful economy.

Silk is also used for sailplane covering.

Brads

If brads are to be left in timber after construction is completed, they should be of brass. When they are used in conjunction with external strips of wood, and are removed after the glue is set, steel brads may be employed. A magnetised hammer can then be used which facilitates the work.

If steel brads are allowed to remain in timber, corrosion is bound to set in, with the result that the wood surrounding the brads becomes ruined.

Dope

Transparent dope is nearly always used for sailplanes and gives a smoother finish than aluminium dope. It should be applied in a temperature of between 65° and 70° F., with forced ventilation, but free from draughts. Special dope is available for application in lower temperatures, but best results are obtained under heated conditions.

The dope should be well stirred both before and during use, and too much should not be taken on the brush.

The first coat should be brushed well into the fabric to ensure proper adhesion, and should be laid on in sections.

Subsequent coats should be evenly laid on, each preceding coat being thoroughly dry before starting the next.

Three or four coats of dope and one of varnish are recommended. One gallon of dope covers about 8 sq. yds. of fabric, and adds about $1\frac{3}{4}$ or 2 oz./sq. yd. to the weight.

The tension of doped fabric is between 2 and 4 lbs./in. run.

Spliced Joints in Timber

Splicing of timber may be done for spars, longerons and struts, if properly made, and if the joints are properly placed in relation to the loading of the structure.

The splice should be a straight scarf joint with a slope not coarser than 1 in 9.

The strength of a well-made spliced joint is about 80% that of a corresponding solid member.

Longeron splices may be made with four pegs, or bolts, evenly spaced, glued and bound with tape. The splice should not be at a joint where other members join, but should be between this and the mid-bay position.

Spar flanges should be spliced at points of inflection, and web splices between the inflection points and, if possible, where local stiffening exists.

Launching Elastic

Normal $\frac{5}{8}''$ diameter rubber shock absorber cord is generally used for hand launching.

The cord consists of multiple rubber threads tightly encased in two coverings of cotton braid.

The load required to cause a 100% extension is roughly 200 lbs., and this is the normal strength of each launching crew with a single rope.

If the rope is to be retained in good condition it should not be stretched beyond twice the original length.

Wires, Cables, etc.

Tables of sizes and strengths are given in Appendix VII.

PART III

SAILPLANE PILOTAGE

CHAPTER XIV

The Soaring Site

Winds, Direction and Velocity—Wind Roses—Dimensions of Site—Site for Distance Flights—Launching and Landing.

Sailplane flights are started from hill sites or, when the initial height is obtained by aeroplane or auto-towing, from flat level stretches such as aerodromes. When mechanical launching has superseded the ordinary manual launch it may become more usual for starts to be made from level ground than from hill-tops.

The requirements of a hill site are described here.

The ideal site consists of a hill, ridge, or series of hills, with the best slopes facing the prevailing wind, which is S.W. in Britain.

If suitable slopes can be obtained facing in all directions, then soaring flight is possible on all days on which sufficient wind is present.

Winds—Direction and Velocity

The factor of greatest importance is the wind, and all available statistics for any particular district should be obtained. If these are studied, together with a map of the site, a fair estimate of the number of days on which soaring will be possible, and the most suitable periods, can be made.

For England generally the prevailing wind is S.W., except for March, when strong winds from the N.E. and S.E. are common. From September to February winds are fairly constant from the S.W., with some intervals of northerly winds, and are of considerable intensity; in fact this period would appear to be the most suitable for soaring, certainly in the south-eastern parts of England.

During April the winds are variable, of moderate intensity, and blow from practically all directions, except E. and N.E.

East winds are very rare, except for the month of March, so that hills facing in this direction are the least valuable. A site which makes flying possible for winds from N.W. through W. to S. is nearly ideal, and there would be very few suitable flying days that could not be utilized on such a site.

During the summer months winds are light and are mainly from the S. or S.W. with northerly periods.

Owing to the formation of sea-breezes the winds in coastal districts become modified to some extent.

It may be mentioned that the wind changes direction with height, through a clockwise movement, so that clouds moving across the site, at a height of 3,000 or 4,000 ft., generally make an angle of 30 to 45° with the ground wind.

Wind Roses

Figs. 144 and 144A, show wind roses for the London Gliding Club grounds at Dunstable in S.E. England, for the period January to June, which have been specially prepared for gliding, from observations carried out by the author. The distance apart of the rings, radially, represents one day, while the intensities of the winds are denoted by the width of the column.

The wind columns have been drawn on the side from which the wind blows, so that if the diagram is used in conjunction with a map of the site, the value, from a soaring standpoint, is easily recognised.

The intensities of the wind have been divided into four grades of the following approximate velocities: slight, 5 to 10 m.p.h.; moderate, 10 to 20 m.p.h.; fresh, 20 to 30 m.p.h.; and strong, 30 to 40 m.p.h. These velocities represent the values at the hill-top.

Soaring can be carried out generally in all winds except slight, and on the site under consideration flights have at times been made in slight winds with very efficient machines.

By reference to Fig. 145, which represents the gliding site, it will be seen at once which winds are suitable for soaring. These have been shaded and are from N.N.W. through W. to S.S.W., although soaring in a N.N.W. wind is rendered difficult on account of the protruding hill at the northern end. On the other hand, the cup known as Pascombe Pit collects the wind, and thus often makes soaring possible over the cup in S.

winds. On such occasions the wind is deflected round the hills on the southern end of the site and is forced up the gap.

The region to the south of the launching ground would be good for N.W. winds, but the presence of electric high power cables makes low flying dangerous in this vicinity, so that it is only used after sufficient height has first been obtained.

The wind roses show that soaring is possible for 131 out of 365 days, excluding flight in S. winds, or a percentage of roughly 36 for the whole year, although the if best part only of each day were selected, the figure would be brought nearer to 50%.

The height of the ground at the top of the hill is just over 700 ft. above sea level, and at the immediate base is 500 ft., although the land continues to slope away towards the W., with the loss of a further 100 ft.

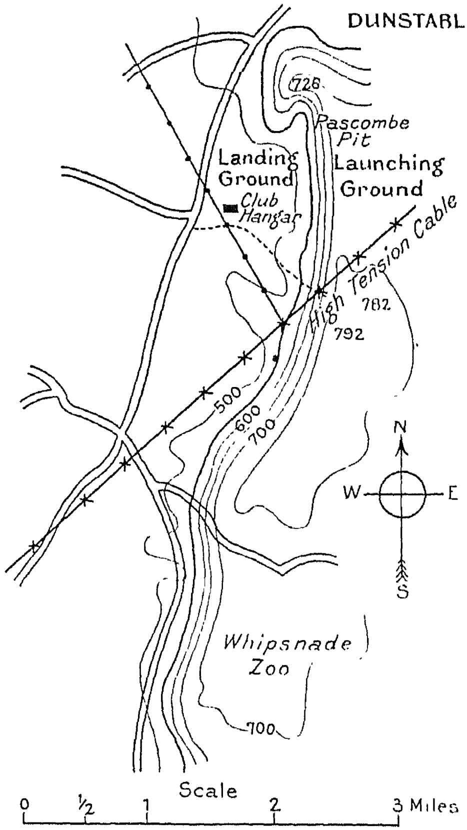


FIG. 145.
London Gliding Club Site at Dunstable.

There is not likely to be any very appreciable difference in the wind roses for the south-eastern part of England, so that Fig. 144 can be taken as a fair indication for this region.

Dimensions of Site

The first consideration is height above the surrounding

country as this affects wind velocity, the upward component present, and the magnitude of the soaring region. The wind speed at the top of a hill, of about 200 ft. in height, may be approximately double that at the base.

For best results the hill should be of very considerable height and well clear of all neighbouring obstacles, such as other hills, trees and buildings, but, providing the surrounding country is fairly flat, good soaring conditions will be found with hills of 100 or 200 ft. in height. As illustration, it may be mentioned that the western slope of the Wasserkuppe hills is well over 1,000 ft. in height and more than 3,000 ft. above sea level, although the sand dunes of the Rossitten site are no more than 100 ft., but since they are situated on the Baltic shore, where high winds from the sea prevail, the conditions are very suitable.

For preference the slope should not be too bluff, such as a vertical cliff, as eddies are formed by the hill face, and on top of the hill, which cause considerable danger to aircraft owing to the downward air currents and the turbulence set up. This is shown in Fig. 146, and it will be noticed that conditions are quite suitable provided that the machine is kept well away from the cliff face and top.

This eddying effect can be seen by standing at the foot of a cliff on the windward side. If a steady wind is blowing it will be noticed that grass, or small objects, are blown away from the hill, but as a gust approaches the direction is changed towards the cliff. As the gust subsides, conditions are unsettled for some seconds, after which the direction becomes once again away from the hill.

A large part of the wind momentum in this area is dissipated in the formation of eddies.

It would be thought that a slope, making an angle with the horizontal, just greater than the gliding angle of the sailplane would be sufficient, providing also that the wind velocity equalled the forward speed of the glider, but in practice a coarser slope is found necessary.

A ridge of shape resembling Fig. 147 has both windward and leeward eddies, and is not very suitable, besides which a reasonably flat top is required for launching purposes. Fig. 148 shows a hill that would provide good soaring conditions for winds of two directions, with an absence of serious eddies, and

possesses besides a good top surface for launching and landing.

The next consideration concerns the length of ridge along which soaring flight can be made. Height is lost on turns, and hence it is obvious that the difference between being able to

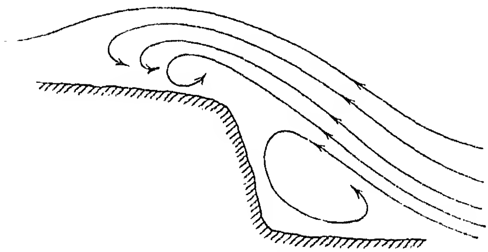


Fig. 146.—Air-flow over Cliff.

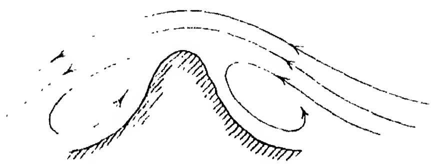


Fig. 147. Air-flow over Narrow Ridge.

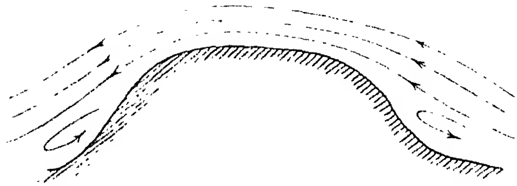


Fig. 148. - Air-flow over Flat-topped Ridge.

soar in a light wind and failure to do so may often be dependent only on the length of ridge. Apart from this, a short ridge is less efficient owing to the " spilling " effect of the wind at both ends.

The ridge should be at least half a mile long, and longer for preference, if sufficient height for distance flights is to be obtained.

Site for Distance Flights

The easiest method of making long flights is by contour soaring, and consequently it is very desirable that a long ridge, or number of hills, should connect with the main site. A ridge of several miles in length, such as the northern side of the South Downs, provides the best conditions for long flights requiring no great amount of skill, but sites of this nature are generally "one-wind" sites, that is to say are available only for distance flights for winds over an angle of roughly 90°, so that the directions of such flights are very limited.

A hill forming one of many hills enables long flights to be carried out in all winds, providing there are suitable launching places available, but greater skill is required to negotiate correctly the various hills and wind currents.

Convection and cloud soaring flights may be made from sites of limited area, but, even for these, conditions seem more favourable over a large expanse of hill country.

The existence of a cup, or cups, on a site is a valuable asset. By this is meant a hill of a horse-shoe shape which collects the wind as a funnel, and thus produces a strong up-current of air. The jaws of the horse-shoe should be wide apart to prevent the formation of dangerous eddies, and it should be noted that unless the wind is blowing directly into the cup, there are likely to be set up turbulent air currents.

The cups provide good soaring conditions, besides which they form very suitable starting points for distance flying.

Launching and Landing

It has already been mentioned that a good flat surface is necessary at the top of a hill for launching purposes. There should be a good clear space, devoid of obstacles such as bushes or fences, facing in all directions for which soaring is possible, and should include an area of fairly level ground for landing.

The ground at the base of the hill should be suitable for landing, clear of rocks, fences, etc., as it is not always possible to land at the top.

A larger landing ground is required below the hill than at the top because the higher velocity wind on top reduces the

ground speed and enables better judgment to be made. Also, if the pilot is unable to bring his craft to ground at the desired spot, on the hill-top, he is able to continue in soaring flight and make another attempt, whereas, of course, this is impossible at the base.

CHAPTER XV

Piloting a Sailplane

Launching—Mechanical Launching—Turning—Soaring—Speed of Flight—Landing.

These notes apply to the flying of sailplanes, but are also applicable to intermediate types of gliders and to primary training machines if used for soaring flight.

It may be as well here to add that elementary gliders are not designed as soaring machines, and are most inefficient for use as such, but soaring flights of considerable duration are possible when both the wind and terrain conditions are exceptionally good.

Launching

The launching of a sailplane is very similar to that of an ordinary glider. A fairly smooth piece of ground should be chosen at the summit of a hill or as near the top as possible, and the machine placed almost directly into wind about 100 yards back from the brow. This allows the crew a clear run on fairly level ground and enables the sailplane to cast loose at the top of the hill and thus to take fullest advantage of the up-currents there. A further advantage is that the machine rests in comparatively still air prior to the actual take-off. The sailplane should be held down until the pilot is seated. A crew of about 14 is generally necessary, which allows for one on the wing-tip and between two and four holding back at the tail. The tail group can be dispensed with if an automatic release is employed, but the man-power method is to be preferred if obtainable, as it has been proved safer by experience. Where an automatic release is used the sailplane has to be specially fitted with a suitable device for attaching to a ring which is firmly secured to the ground by a large peg or pegs. This usually takes the form of a hook attached at the back of the skid, which may be either released by the

pilot or released automatically, as the pull reaches a certain predetermined amount, at the desired moment, so that it falls back and enables the ring to fall off.

Some elastic or spring arrangement should be incorporated in the anchorage so as to reduce the sudden shock on the machine (and pilot) when it is cast loose.

Automatic releases have been manufactured which take the form of a box inside which are rings of stout elastic. As the launching force increases the elastic rings stretch till a point is reached where the holding-back ring is allowed to come off the hook. By adjusting the position at which this takes place the tension of the launching pull may be set at any desired amount between, say, 200 and 400 lbs.

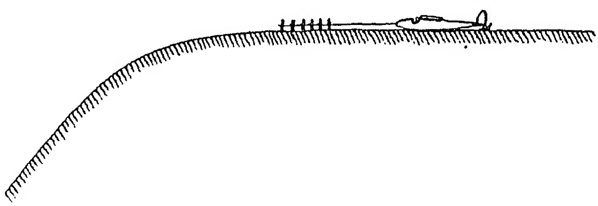


FIG. 145. Launching a Sailplane.

Such a release overcomes the necessity of a tail crew and becomes essential when the starting team is strictly limited, but necessitates the fixing of stakes at the sailplane's point of departure, and, therefore, as mentioned above, if a sufficient team is available it is preferable to use members of the crew for this duty. A car with wheels left securely locked can be made to serve for anchorage and has the advantage of being easily moved to another position.

It is not wise to employ less than ten men on the launching rope if a good, safe take-off is required, as sailplanes are somewhat heavy, besides which the main plane is so set that it makes a fine angle with the ground, which means that the highest lift coefficient, for the wing section of the glider, cannot be utilized, and in consequence the taking-off speed is greater. (See also the paragraph dealing with the wing attitude on page 28.)

The elastic may be either single or double, preferably the latter, of length about 80 ft. from the hook to the end, opened

out at an angle of roughly 30°. When double elastic is used the number of the crew may either grip both cords or the crew may be divided so that each half takes one strand.

As many as seven or eight men may be placed on each leg of the launching rope to ensure a strong pull-off, so that a good initial height may be gained. This is of importance when soaring is difficult.

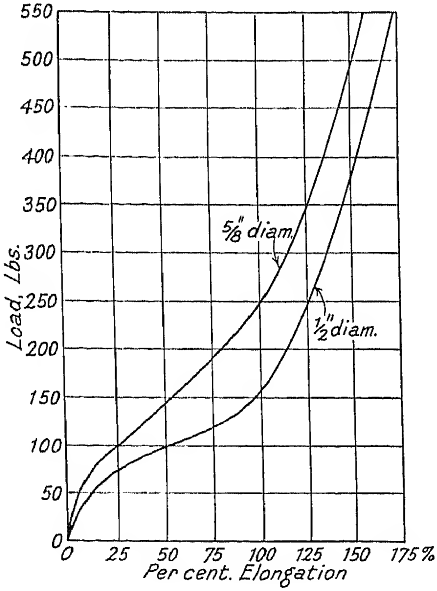


FIG. 150.
Characteristics of Shock-absorber Cord.

The launching elastic or shock-cord should be of good grade shock-absorber elastic of $\frac{5}{8}''$ diameter, or $\frac{1}{2}''$ elastic may be used where the elastic is doubled.

The elastic should never be stretched beyond twice its original length, or both the rubber and the cotton covering will be damaged.

Fig. 150 shows typical curves for the energy required to stretch $\frac{1}{2}''$ and $\frac{5}{8}''$ elastic cords by 100%, from which it will be realised that the larger size needs a force of about 260 lbs. to stretch to twice its length, and the smaller 150 lbs.

Assuming a "V" angle of 30° and a single rope, the force in the direction of flight becomes $2 \times 260 \times \cos.\ 15°$, or about 500 lbs. The necessary holding-back force on the tail will be about 100 or 150 lbs. less owing to ground friction.

As the glider leaves the ground the crew continue to run so that the launching force is retained for a longer period. The commands for the start, which are best given by the pilot, are the same as for elementary work; these being "walk," "run," "release." The number of walking steps taken by the crew should be between 15 and 20, according to the strength of the team, and should be counted by the pilot before giving

the command, "run," and the word "release" is given just afterwards, when the sailplane shoots swiftly forward. In a high wind or where the start crew pass from the pilot's view it is a very sound plan for all members of the team to count aloud the walking steps, and on reaching the pre-agreed number, say 15, all yell aloud "run," and commence to run forward.

If the launch is made slightly side-wind, that is with the nose turned towards the direction in which the flight is to be made, it will be found that the initial turn is made easier.

Main Plane Loading During Take-off

The angle of attack should be kept low until the launching rope falls clear, after which a climb can be made so that the greatest altitude is obtained.

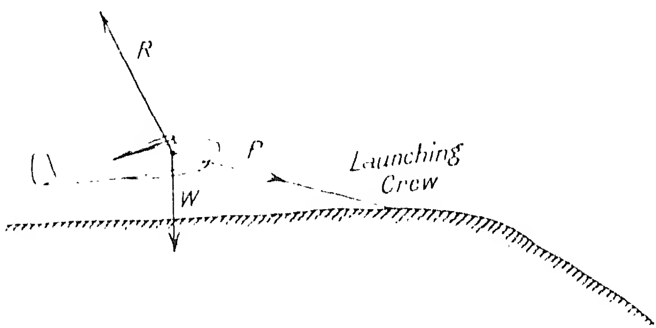


Fig. 141. Sailplane Loading during Launch.

The loading on the main planes is greatest if the climb is commenced before the rope is detached. For these conditions the centre of pressure is at or near the C.P.F. position.

The flying speed during the launch is in the neighbourhood of 40 m.p.h. It should be noted that the wind speed alone may be as high as this, in which case a gentle launch should be employed.

The maximum main plane load will then be

$L = .0024 \times K_L \times A \times V^2$, and giving suitable values to K_L, A and V,

$L = .0024 \times .7 \times 200 \times 60 \times 60$

$= 1{,}210$ lbs.

Now the wing is designed for a load equal to its own weight, plus the loaded body weight multiplied by a factor, or, say, $200 + 300 \times 6 = 2{,}000$ lbs.

From this it is seen that a strong launch in a high wind can impose loads very close to the designed figures.

Taking-off

On the word "release" the crew continue to run, and the sailplane leaves the ground almost immediately, but, should it fail to do so, the pilot should assist by pulling gently on the stick. As soon as it is air borne the stick should be held slightly forward so that the machine keeps parallel to the ground and so obtains the maximum power and speed from the pull off.

If the start has been correctly judged the shock cord should fall off just before the sailplane reaches the lip of the hill, and the control column may be pulled well back for a short period. The high forward speed, together with the entering of the region of rising currents, enables the machine to climb to a considerable height, perhaps to 50 or 100 ft., when the stick is moved to a position just forward of neutral. The end of the climb can be easily judged by the falling-off of pressure on the elevator, and on no account should the machine be allowed to reach stalling speed. Apart from the danger accompanying a stall, practically the whole of the initial height is lost.

The take-off should have been made directly, or nearly so, into wind, but as soon as height has been obtained the pilot should turn sharply to right or left so as to travel parallel with the ridge or hill-top.

Mechanical Launching

Owing to the large crew necessary for the ordinary manual launch, and the labour involved, many attempts have been made to evolve a satisfactory and simple launch with the aid of mechanical power, generally motor cars.

No completely satisfactory method has yet been obtained, although considerable success has been achieved. Most methods are accompanied with an element of danger, not present with the manual launch, and for this reason mechanical launching is not yet popular.

There are several possible arrangements for launching by motor car, but only two are at present recommended by the

B.G.A. (See Appendix III for the B.G.A. Regulations governing mechanical launching.)

In the first method the motor car is connected to the glider with a double length of elastic cord and a length of at least 100 ft. of cord or cable. If the cable is placed between the elastic and the glider, there is little likelihood of either the pilot or the car driver being injured in the event of a breakage of the elastic cord.

To prevent over-stretching of the elastic, a small flag, or other suitable mark, is fixed to the ground in such a position that the release can be timed for operation as the elastic is stretched to twice its normal length.

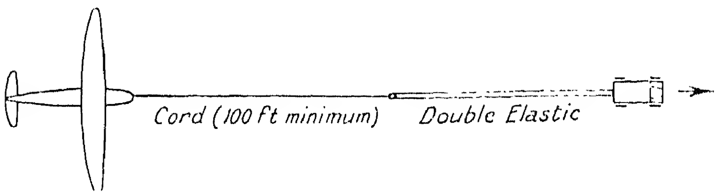


FIG. 152. Mechanical Launching.

Apart from this the launch is made in the usual manner. After the release the car turns off to one side.

The chief difficulties with the method described are that the start has to be made at a considerable distance from the edge of the hill, which may amount to 300 ft. if the wind direction is perpendicular to the hill, and also a long runway of level ground is required. These difficulties are obviated to a large extent in the following methods:

In one, the elastic is pegged securely to the ground at one or two points forward of the glider, a car is attached at the back of the glider and pulls the glider backwards. At the release the glider shoots forward.

This is somewhat disconcerting to the pilot, and the additional power gained in the previous methods by the crews or car continuing to move forward after the release is not present here. It is, of course, essential to have someone stationed at the wing-tip to retain lateral balance before the start.

In another method, the second B.G.A. approved method, the cable is attached to the glider and is passed forward and

round a pulley where it is joined to the elastic, which latter, in turn, joins to a car. The car is then driven in a direction at right angles to the course of the glider. The glider is held back in the usual way and is released when the elastic becomes extended to double length.

Variations of this method are obtained by driving the car back towards the glider, but to one side, or by inserting a second pulley near the glider so that the car can go forward by the side of the glider.

The disadvantage of any method in which a pulley is employed is that the glider is being pulled downwards the whole time, the downward component being increased as the machine

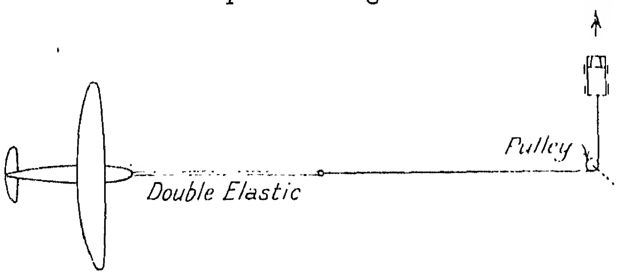


Fig. 153.—Alternative Method.

gets closer to the pulley and, because of this, the length of rope should be large.

Stationary motor cars, or engines, with winding drums attached have been used in place of the moving cars.

Two cars have been employed in place of the usual crews, so as to form a " V " with the glider, but, on account of the large possibility of uneven acceleration of the two cars, this method is dangerous.

A wise precaution with mechanical launching is to have a cable release arrangement fitted so that in the event of excessive speed the pilot can throw off the cable.

It seems only reasonable that an efficient mechanical launching apparatus, perhaps on the lines of the aeroplane catapult, should be developed for sailplane work. This should do away with the use of large crews, motor cars and elastic ropes. At the same time the possibility of a light rocket launching apparatus should not be lost sight of, as this might have the added advantage that sufficient height could be

attained even from flat ground for the start of convection or cloud-soaring flights.

Turning

At the edge of the ridge or at some distance from the starting point it becomes necessary to turn and go back. If the wind is fairly high it will be found that gentle rudder pressure on the side into which the turn is required quickly brings the machine facing into wind, but it seems to have no desire to continue the turn past that point. This is due to the weathercock stability of the machine, and the completion of the turn can only be accomplished by holding down the nose slightly, to increase speed and controllability, and then giving full rudder and a little aileron or bank.

When flying in a wind of small velocity, the flying speed for best retaining height will be little higher than stalling speed and this should be increased by placing the machine in a diving position before commencing the turn. The turn is then commenced with a little aileron and full rudder almost simultaneously. As soon as the turn is started over-banking should be prevented by holding-off, as when flying a power machine. This is done by moving the stick in the direction opposite to the turn, but if it is overdone the turn is interrupted and cannot be readily recommenced. The stick can now be pulled gently backward again so that at the conclusion of the turn normal speed will be regained. When the turn is completed neutralise all controls and if the speed is still on the high side it can usually be converted into a slight gain of height. It is a good plan to choose a point of strong up-current for turning, as the height lost is often sufficient under poor conditions to make soaring flight impossible.

The practice of gaining speed prior to a turn, not only very naturally assists the turn, but is also a wise precaution as it prevents the possibility of stalling and spinning. Sailplanes should not be banked at a high angle, since a greater angle of bank means a smaller vertical component of lift from the wings, and consequently a greater loss of height results. On the other hand, no bank, or too little, prevents the turn from being made and may develop into a spin so that just sufficient aileron control, to enable the turn to be effected, should be applied and no more. The effect of increasing speed before

a turn, and thus enabling the elevator to be used for assisting, will be found most advantageous. Increasing speed during a turn causes the elevator to act against the turn and thus prolongs it.

Soaring

A straight flight without loss of altitude can be made in very little wind, say about 10 m.p.h., but as soon it becomes essential to turn back along the hill-side a considerable loss of height is inevitable, so that a higher wind velocity of 12 or 15 m.p.h. is required.

At about 12 m.p.h. wind speed soaring is not very easy, and it is with difficulty that the initial height of the launch is retained. A false movement or manœuvre may mean a descent to land, added to which local down-currents are often responsible for disaster under these conditions.

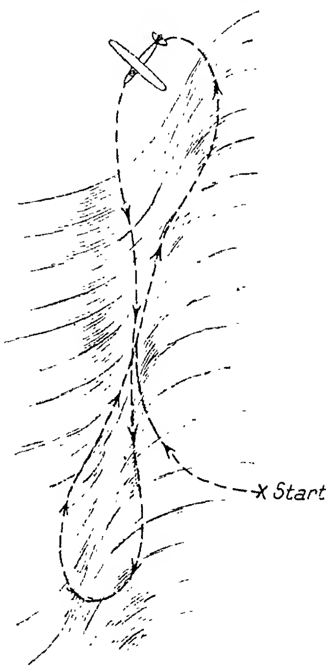


FIG. 154.
Contour Soaring—Sailplane's Course in Light Wind.

At higher velocities, up to about 30 or 35 m.p.h., soaring is much easier and safer, far greater heights can be gained, and the margin for mistakes is much larger.

The course followed in a light wind is indicated in Fig. 154, and takes the form of a flattened figure "8." The sailplane speed relative to the ground is high. A course practically close to the hill is kept until the commencement of a turn, which is always made away from the hill, after which the hill-side is regained ready for the next turn.

The high speed, continual turning, and poor soaring qualities call for the utmost skill on the pilot's part and flight under these conditions is not very pleasant if the soaring area is small.

As the wind increases in velocity the sailplane's speed

relative to the earth is lessened. To follow a course parallel to the hill-side the machine is pointed out towards the valley and moves along sideways in a crabwise manner, the course being as indicated in Fig. 155. The return journey may be made by turning the nose of the machine though only a few degrees and may be accomplished by rudder movement only, the greater the wind the larger is the angle the sailplane makes to the hill-side, and the smaller is the angle of the turn.

As soon as the wind speed becomes as great as that of the sailplane, the attitude of the machine relative to the hill face may be perpendicular, so that hovering is possible.

Altitude is gained by moving backwards and forwards along the ridge, as explained above, taking advantage of all gusts and favourable air currents, until the maximum height, under the conditions prevailing, has been obtained.

At a height of approximately 100 ft. above the hill the air is much steadier than it is closer to the ground, so that a much more constant speed can be maintained and conditions are more pleasant. The change over to settled conditions is very noticeable.

If conditions are suitable and the height seems sufficient, a distance flight may be embarked upon and may be extended by any of the methods explained in the chapter dealing with soaring and sailing flight. (Chapter XVI.)

When the wind velocity is in the neighbourhood of 40 m.p.h. or higher, the sailplane is liable to be blown backwards, making extreme care necessary, and only pilots of considerable experience should attempt to fly in such winds.

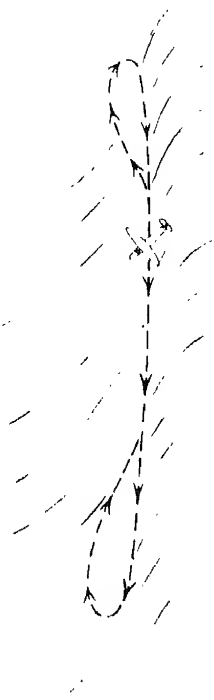


FIG. 155.—Contour Soaring Sailplane's Course in Strong Wind.

Speed of Flight

The speed at which least height is lost per unit of time, is generally about 3 or 4 m.p.h. faster than the minimum, or stalling speed, which means that

greatest height may be gained in an up-current when flying at this speed.

Immediately after launching, and the first turn along the ridge, the sailplane should be held at the speed for minimum loss of height. With most machines this is about 32 m.p.h.

As height is gained the speed may be increased slightly if desired, so as to leave a larger margin above stalling speed, but if the maximum height is to be obtained for commencing a distance flight, the lower speed should be maintained throughout. Also in very gusty winds a higher speed should be used, or stalling is liable to take place, as the wind velocity drops after gusts.

After leaving the source of lift, the sailplane should be kept at the velocity corresponding with its best gliding angle, usually about 3 m.p.h. above the velocity for minimum sinking speed, or say 34 to 35 m.p.h., as this is the speed at which the maximum distance can be flown from a given height.

This does not, however, allow for the speed of the wind. The sailplane speed should be increased if flying against a head wind and decreased slightly for a following wind, but never below the speed for least loss of height.

The reason for the change in flying speed to allow for head winds is easily explained. Suppose the speed for best gliding angle is 35 m.p.h. and a head wind of equal velocity were encountered, the ground speed of the machine would be reduced to nil and a slow vertical descent would result. Now if instead the sailplane speed were increased at the expense of a coarser gliding angle, definite headway would be made, equal to the difference between the velocities of the air and machine.

If the angle of glide for all velocities is known, the optimum speed for any particular wind can be found, and a speed diagram for any one type of machine can be prepared.

Landing

The landing may be made either on top of the hill, at the starting point, or somewhere on the lower ground if the pilot has failed to soar, or again at the end of a distance flight the landing will be made when and where the flight can be continued no longer, due to lack of suitable up-currents or darkness.

To effect a landing at the starting point the pilot has to contend with the higher wind at the top of the hill, and has to

lose height in the ascending air flow. The best way to do this is to fly well behind the starting point, where it will be found that the wind speed is less, and then place the machine in a slightly diving attitude. The steepness of the dive will depend on circumstances, but should not be very great, or the air speed of the sailplane will be increased to such an extent that landing becomes almost impossible. On nearing the ground, if the speed is rather high the machine should be held level a few feet off the ground for some seconds, so as to throw off the excess of speed, when a normal landing can be made. An experienced pilot can run the nose of the sailplane along the ground with the tail still 2 or 3 ft. up, so that the friction of the ground helps to reduce any excessive speed.

Instead of flying behind the starting point, and if the hill-top is clear for some little distance, the descent may be made by gliding across wind along the top of the ridge until sufficiently near the ground when a turn into wind and a landing can be made.

Behind the crest of a hill there is often a down current, due to the curl over, or burbling, of the wind, which may assist the pilot in his descent. If the machine is over-shooting the desired landing point, owing to the high velocity wind, the pilot should commence to soar again, and make a further attempt to land at the desired spot.

A landing at the base of a hill is not so difficult, since the pilot may pick out a suitable spot when still well up and approach in a series of "S" turns. As the wind velocity here is much less than at the top, and has little, if any, vertical component, it does not tend to prolong the flight.

In the case of the finish of a long-distance flight, unless flying near quite open country, the flight should not be continued until the last possible moment.

As soon as the pilot feels that the flight is practically at an end, and sees that there is no chance of regaining height, he should make up his mind to land, and choose a field or other suitable ground not too far ahead, and land in the usual way.

Landings need not always be made into wind, although this is the safest and easiest method. Providing the wind speed is not too high, down wind landings are quite safe, and are often done. If the normal landing speed of a machine is 30 m.p.h., the ground speeds, against or with a 10 m.p.h. wind,

are 20 and 40 m.p.h., respectively, and although the difference is considerable, the highest landing speed is still low compared with power craft. The excessive speed of a down wind landing is best reduced by gently pushing the main skid against the ground surface, so as to cause a fairly rapid and smooth retardation.

Side wind landings at any angle to the wind are often seen, and can be successfully accomplished in an emergency, providing the wind speed is moderately low, but otherwise they are not to be recommended, as an undue stress is thrown into the landing unit, often resulting in structural damage. Ground which gently rises in the direction of landing greatly shortens the length of glide and run, and should be chosen, when available, for this reason. Conversely, ground which falls away increases the difficulty of landing.

A good method of losing height, for landing, is by means of side-slipping, or a series of side-slips, first to the left and then to the right. The tail is moved alternately from one side to the other, together with "bank," the machine being held, by means of the rudder and elevator, in this position for a few seconds only before crossing over to opposite side-slip. It will be found that height can be reduced, without any excessive gain in forward speed, even in the up-current at the hill-top.

This method is much preferable to a continuous side-slip to one side, since sailplane fuselages do not cause very great resistance to the air when flown sideways-on, apart from which the approach can be judged far more accurately with a series of side-slips.

A field of long grass, or corn in an emergency, enables a quick, safe landing to be made. Height can be lost by gently diving to within a few inches of the ground when the machine is held level, so that the friction of the grass, or corn, with the fuselage quickly reduces any excessive speed, and brings the sailplane to rest.

If a pilot gets into difficulties, owing to disturbed airflow or down currents, and a forced landing has to be made at short notice, the pilot should face into wind at the first opportunity. The lower speed over the ground enables better judgment to be exercised while manœuvring for landing, apart from the obvious advantage of the reduced ground speed at which contact is made.

FIG. 156.—Sailplane on Cross-country Flight.

[To face page 190.

CHAPTER XVI

Methods of Soaring and Sailing Flight

Hill, or Contour, Soaring—Convection Soaring—Cloud Flying—Storm Soaring—Gust Soaring, or Dynamic Flight.

Soaring flight is flight in which height is maintained for a considerable period without the aid of a motor or other mechanical means. It can only be carried out in ascending air, in air moving with an upwards component, or in winds of fluctuating velocity.

Soaring, with the exception of "dynamic" soaring, is really gliding, and the machine (or bird) is actually descending the whole time, through the ascending air. When the rate of descent, or glide, is small, and the rate of ascent of the air is equal to, or exceeds, this quantity, then soaring is possible.

Sailing flight may be made either by soaring during the whole time or by alternately soaring and gliding. It differs from pure soaring in that continuous progress is made away from the starting point.

Since soaring, generally, is dependent on an ascending current of air, it may be accomplished with the aid of any atmospheric or physical condition causing the air to rise.

It has been claimed that some birds are capable of soaring in still air, or air with a purely horizontal and constant velocity, but this has not been proved. A horizontal wind moving over the earth with a warm surface tends to rise slightly, so that the vertical component is present, and again the birds that are observed to soar in apparently still air are always found in tropical countries, and here the air is warmed by radiation from the earth's surface, causing expansion and upward movement.

The sun's rays do not heat the air through which they pass, but the heat is extracted by the earth's surface, which is partly transmitted to the earth, or rock, below the surface, and partly radiated into the atmosphere. As the air cools after

sunset, the stored up heat in the earth is slowly given up again to the surrounding air.

The vertical movement in the air is imperceptible to man, especially close to the ground, and this accounts for the soaring observed in apparently still air. This is borne out by the fact that soaring birds are always seen to descend shortly after sunset, and do not rise again until the air has warmed up again, on the following day.

This effect is also noticeably felt in gliding with man-made machines, as soaring is always much easier after mid-day. There are at present five known methods of soaring, each of which is described below. Distance or duration flights may be carried out by any one method or any combination of methods.

Hill, or Contour, Soaring

The best and earliest known is hill soaring, which is simply explained by the upwardly deflected current of air over a hill, cliff, or similar obstacle.

The resultant of the sailplane velocity with that of the air indicates the actual path of the sailplane.

Fig. 161 illustrates this, and shows the difference between the path of the machine when flying into wind and down wind. In the former case the velocity of the machine, relative to the earth, is approximately the difference between the gliding velocity, in still air, and the wind speed, whereas in the latter it is the sum of the velocities.

This brings out two points: Firstly, that the rate of climb appears greater into wind than down wind, although actually they are the same, and, secondly, that speed relative to the ground is much higher down wind than up wind, and any necessary manœuvre, to miss an obstacle, for instance, has to be started much earlier, when flying down wind.

When the wind speed equals and is opposite to that of the glider, the latter has no speed relative to the ground, and height gained or lost over any one period is the difference between the sinking speed of the machine and the upward component of the air flow. When these are equal, flying may continue without loss or gain of height, and when that of the wind exceeds the sinking speed of the sailplane, then climbing is possible.

Convection Soaring

This method of soaring is the last to be employed by man, and has only recently been successfully achieved, although all tropical birds soar in the convection currents. Nevertheless, convection has undoubtedly been a contributing factor to most extensive soaring flights. Convection soaring would

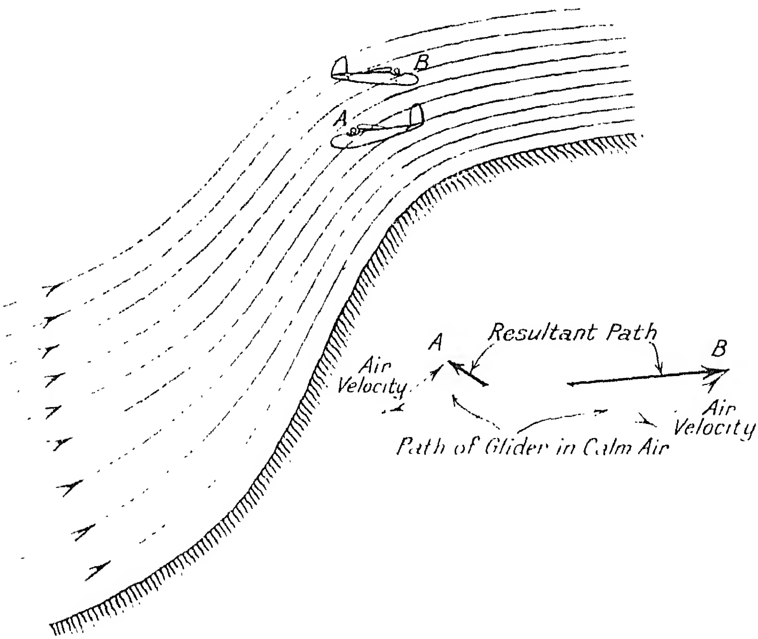


FIG. 157. Path of Sailplane "Against" and "With" Wind.

appear to hold enormous possibilities, and may before long become one of the most important factors in motorless flight.

In tropical countries, the soaring birds make no attempt to fly until the air has warmed up. They then leave their roosts and commence flapping. When a certain height has been gained, the flapping stops and the birds glide in circles, or spirals, gaining height very slowly at first, but, with increase of height, their soaring obviously becomes easier. Tremendous heights are attained, and the return to earth is not made until the evening.

The difficulty with sailplanes has been in the gaining of sufficient initial height over areas where upward convection currents are formed. This has been overcome by towing the sailplanes by means of power aeroplanes and releasing at a height of 1,000 to 1,500 ft., although it is anticipated that some more simple means will be found for gaining height initially.

The formation of convection currents is explained by the heating of the earth's surface, by the sun, which in turn warms the surrounding air, thus causing expansion.

If expansion cannot take place sideways, then it must do so in a vertical direction. As the lower air expands, the layer above is forced upwards, and if this second layer is also warmed, by radiation from the earth, it will also expand, so that the upward velocity becomes greater with height.

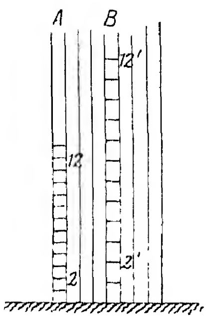


FIG. 158.
Convection Currents, Explanatory Diagram.

If the air is imagined to be divided into vertical columns or tubes, and each tube is sub-divided into small volumes of air, as shown in Fig. 158, then it will be seen that as each small unit expands there is an accompanying upward movement with a velocity that increases with height.

Suppose the conditions before heating are as shown in Column A, and, after heating, in Column B. It will be noticed that the unit denoted by 2 has risen only to 2′, whereas unit 12 has moved up to 12′, such that the difference between 12 and 12′ is several times larger than the distance 2 to 2′.

Actually there is some modification necessary, as the radiated heat decreases with altitude, so that there must be a height at which the rate of increase in velocity becomes nil and above which it tends to fall off again.

There must be a time, or probably more than one, when the earth's surface heat is at a maximum, after which it will remain at this temperature for some period, or may commence to decrease again.

If the temperature remains reasonably constant, the air may retain its expanded condition, and further upward movement will be checked, but if there is an area in which the sun's heat is absorbed, such as water or meadow-land, then cool air

will flow in to the heated area, and will thus enable the vertical flow to be maintained. (See Fig. 159.)

This is, of course, the explanation of the sea breezes, experienced along coast lines during warm days, as the air flowing from the colder to the warmer regions causes a horizontal flow. The cycle is completed by the expanded air flowing outwards, above the cool regions, contracting and descending again.

Conditions such as these are ideal for convection soaring.

Lanchester[1] wrote in 1908: "Suppose the column of heated air is but 1° C. hotter than the surrounding air, then

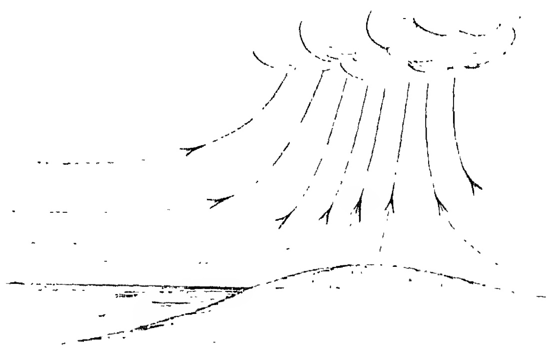


FIG. 159. Sun's Action on Land and Water, showing Cloud Formation.

its density will be approximately 1/300th part less than normal, and if the height of the heated column be 300 ft., the difference of pressure by which it is propelled will be equivalent to a 'head' of 1 ft.; this, by the principle of Torricelli, corresponds to a velocity of 8 ft./sec."

As the sinking speed of most sailplanes is in the neighbourhood of 2.5 ft./sec., it is easily seen that the possibilities of convection flying are enormous. The probable flow of air due to convection currents over a stretch of land of various physical conditions is shown in Fig. 160. Convection flights of long duration can be carried out during warm days by keeping over the land where up-currents would be anticipated and flying round regions of down-currents.

[1] "Aerodonetics," Dr. F. W. Lanchester, p. 257.

Squadron-Leader G. M. Dyott, writing in "The Aeroplane"[1] on his experiences whilst flying in Peru, stated that "The conditions of the atmosphere could be judged very accurately by the careful observation of the flight of turkey buzzards . . . (which) can only maintain flight in calm, still air with considerable effort, and they depend on horizontal or vertical air currents to keep aloft for any time. About eight or nine o'clock in the morning they all leave their resting places and beat the air, sometimes giving it up immediately and losing so much altitude that they would be unable to regain their perch, and would have to take refuge on a lower ledge or some dried-up tree in the valley. As soon as conditions for soaring flight prevailed, they would all be circling and circling until lost in the blue. Invariably they seemed to prefer the sides of the valleys . . . (and) close observation showed that the air in the centre of the valley was almost always descending. Many times I noticed them glide from one side to the other, and invariably this manœuvre was accompanied by a big loss in altitude.

"Towards half-past four all the heat eddies had stopped, and down would come the turkey buzzards to rest for the night. Frequently, if their return was postponed till a late hour, their landing on tree-tops was very strenuous, as, unable to support themselves in the falling air, they would fall like a lump of lead on an extending branch, and there remain till the morning."

This brings out several interesting points. The hours between which soaring is possible are from nine a.m. till five p.m., or roughly eight hours; the rising currents are to be found by the hill-side, causing cooler air to descend over the centre of the valleys, but with a reversal of flow at the end of the day (this is a well-known meteorological phenomenon); and, judging by the weight of the birds, which they, themselves, are barely able to support in flapping flight, and the great heights attained, the conditions must be exceptionally suitable for soaring flight. The possibility of exploiting the atmospheric energy, in such parts of the world, for commercial purposes, seems only reasonable.

[1] "The Possibilities of Air Navigation in Peru," "The Aeroplane," June 18, 1919.

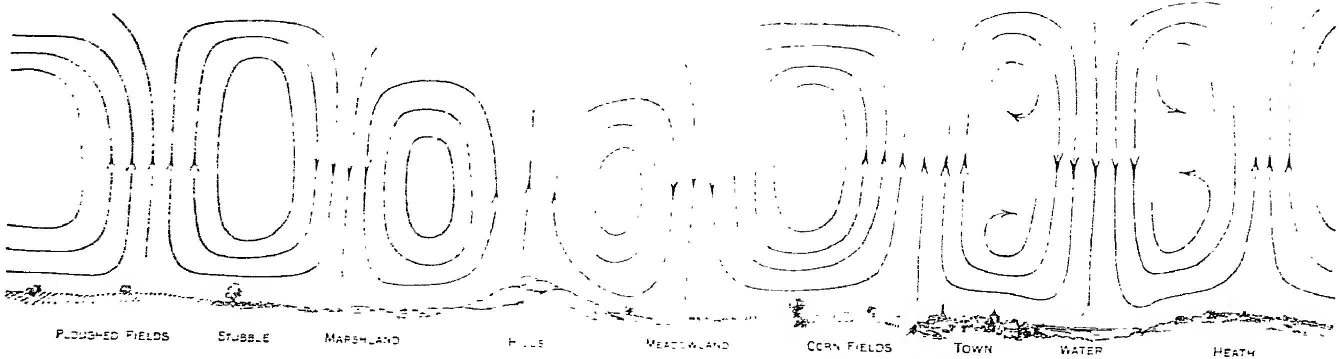


FIG. 160.—Diagram showing Convection Currents.

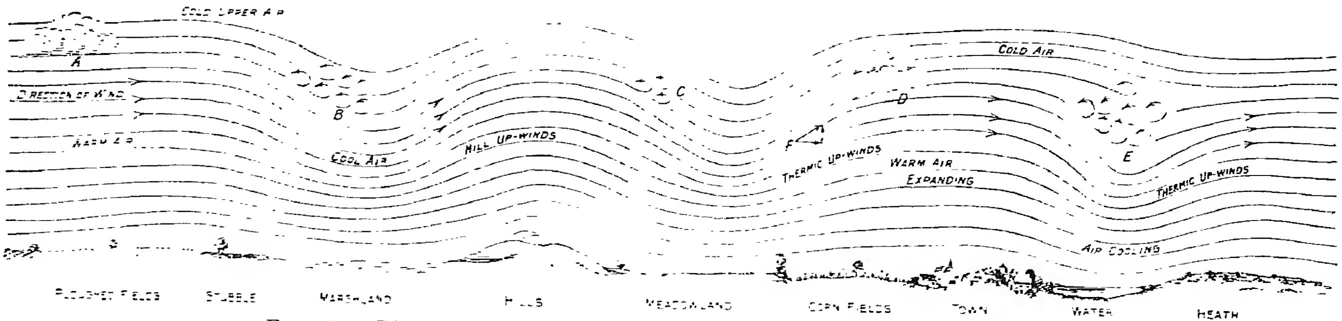


FIG. 161.—Diagram showing Wind and Thermal Currents with Cloud Formation.

Cloud Flying

The presence of vertically moving air streams in and near clouds has been known for many years, but it is only during the past few years that they have been exploited for motorless flight.

Cloud soaring is very closely related to convection flying, as clouds often owe their formation to the effect of convection currents.

It is noticed that clouds often form along the coast, and, in some cases, accurately reproduce the shape of the coast line. They may also be seen forming over ranges of hills and over towns.

In all cases the formation is caused by rising currents, but whereas in some cases the air is deflected upwards by the presence of hills or cliffs, in other cases convection streams are responsible.

The actual formation is due to the condensation of the moisture present in the air on reaching higher and relatively colder regions.

Fig. 159, on page 195, shows diagrammatically the formation of a cumulus cloud due to convection.

The same effect would be obtained by a wind, blowing in from the sea, being deflected upwards by the hills or cliffs near the water's edge.

Fig. 161 is a composite representation of the probable formation of clouds due to convection and wind. The air flow or wind is seldom purely horizontal, but has vertical components due to obstacles on the ground and, of course, the convection flow. If the horizontal wind velocity were known and the velocity of the convection currents at several points, the resultants could be plotted to give a map of the air flow over that area.

At point F, in Fig. 161, if the horizontal velocity is 20 ft./sec., and there is present a vertical up-stream of 10 ft./sec., then the path of the air is as shown.

A wind blowing in a horizontal direction tends to deflect the convection currents in the direction of the wind.

The air flow must have a switch-back motion as shown in the figure, and it is very probable that this causes the actual formation of the clouds and might account for swirling, about horizontal axes, that is known to exist in clouds.

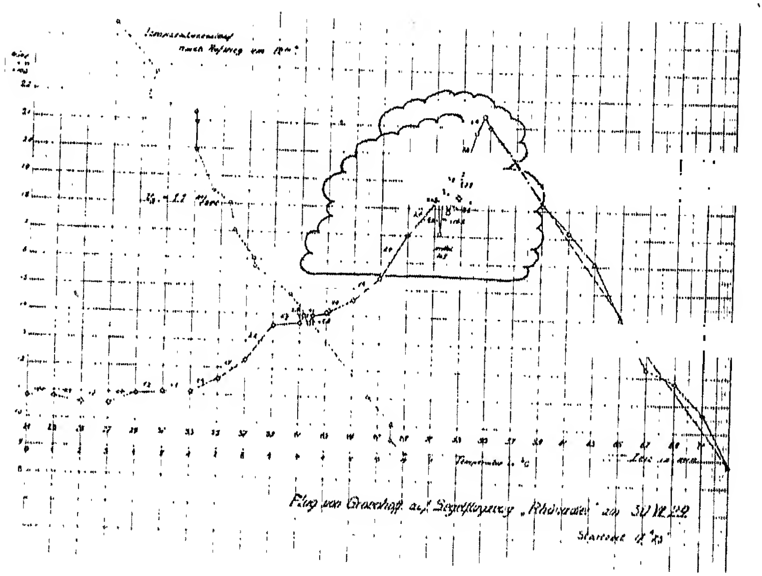


FIG. 162.—33-kilometre Cloud Flight by Groenhoff, with Passenger, July, 1929.

[*To face page* 198.

At A is shown a cloud formed, B and E are clouds forming, while D is the nucleus of a cloud that commenced forming at C and will be added to at E.

The cloud tends to decrease while passing over down-current areas and, over large stretches devoid of substantial up-currents, they may disperse altogether.

Cloud flying was initiated in 1928 by Nehring and Kronfeld, who flew beneath large cumulus clouds, the conditions having been previously predicted and tested out by aeroplanes carrying barographs, which were flown under the clouds with the engines shut off.

These flights were followed up during the next year by Kronfeld and Groenhoff, with excursions through and above the clouds which enabled distances of 150 kilometres and 34 kilometres to be covered, the latter being by Groenhoff in a two-seater machine with a passenger. Both flights were world records.[1]

Violent currents, both up and down, are present in the clouds themselves, although the main velocity is in an upward direction. These disturbed conditions are due partly to the swirling present during the formation of the cloud, and in part to the liberation of latent heat due to condensation.

The liberation of the heat causes a continuation of the ascending current, which probably explains why soaring is possible above the clouds.

[1] See "Ten Years Gliding and Soaring in Germany," Georgii, B.G.A. Journal, No. 1, March, 1930.

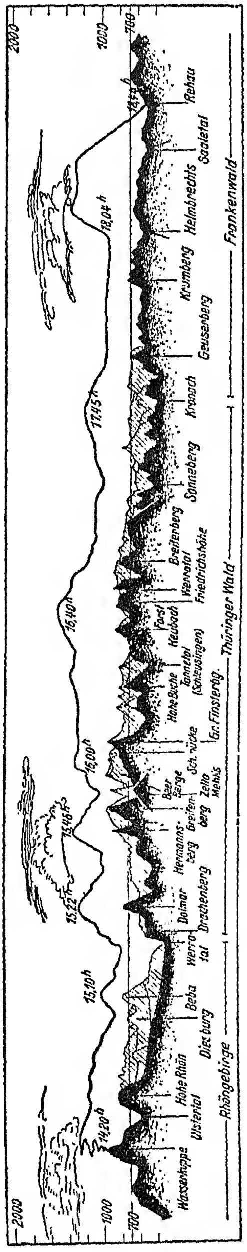
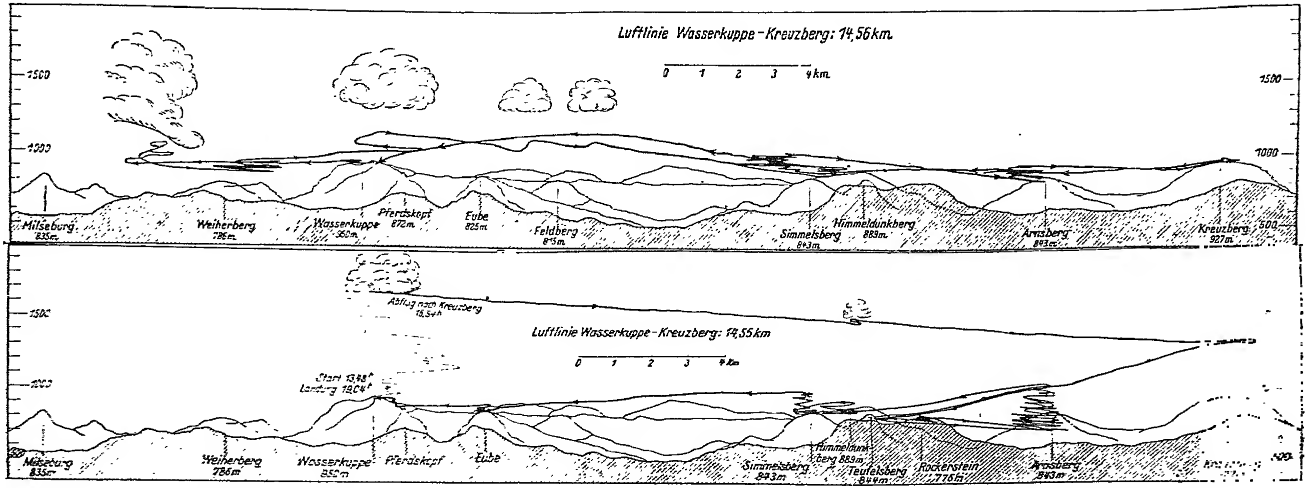


FIG. 163.—Kronfeld's 93-mile Flight from Rhoen to Rehau, 1930.



FIGS. 164–165 —" Out and Return " Flights by Kronfeld and Groenhoff, Wasserkuppe to Kreuzberg and back, a distance of 20 miles, August, 1930.

Storm Soaring

Storm flying is done by soaring in the up-currents preceding a storm or storm cloud. It bears, however, little relation to ordinary cloud soaring.

During a warm day when the air is still, a wedge of cold air is forced along, which drives the warm air before it (see Fig. 166). Up-currents of considerable velocity are thus formed in front of the storm, and it is in this region that sailing flights are

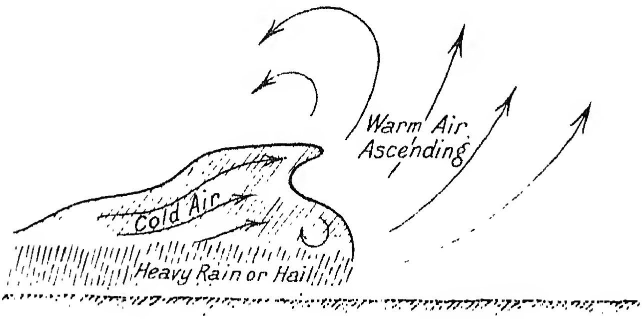


FIG. 166.—Diagram of Thunderstorm.

made, the sailplane keeping the whole time some distance ahead of the storm.

Some of the longest flights have been accomplished by this method.

There are also violent up-currents within the storm cloud as well as down-currents of similar intensity. The intensity of the up-currents is gauged by the size of hailstones which must have been supported before falling to earth.

It is doubtful whether any sailplane could survive a flight within a bad storm, and for this reason it is usual for pilots to wear parachutes during storm flights.

Gust Soaring or Dynamic Flight

Flight by this method has been believed possible for many years and attempts at its accomplishment have been made, but full success has not so far been achieved.

The soaring flight of albatrosses, by which they seem to be able to fly for several days continuously, without any wing movement, has also always puzzled observers, and it seems

very probable that the solution of this may provide the answer to both problems.

As long ago as 1883, Rayleigh [1] laid down the following conditions for bird flight to take place without flapping of the wings: Either

(1) the course (of the bird) is not horizontal (gliding), or
(2) the wind is not horizontal (static soaring), or
(3) the wind is not uniform (dynamic soaring).

The term "dynamic soaring" was first used by Lanchester [1] in 1908, to differentiate between flight in which the velocity of the horizontal wind is variable, and soaring in an up wind of fairly constant velocity, which he termed "static" soaring.

Professor Georgii [2] has stated: "When the horizontal wind is variable, the pilot gains height as the velocity increases and loses height as the velocity decreases. As the air forces are proportional to the square of the air speed, it is possible in principle to obtain a net gain."

Again, in a lecture before the Royal Aeronautical Society,[3] Herr Lippisch gave the following explanation of dynamic soaring flight:

"The bird which flies forward with the help of wing beats receives the necessary forward thrust through the considerable up and down movements of its wings. The horizontal motion implies, then, that the up and down moving parts of the wings follow a path of wave form relative to the air. When the forces are calculated and integrated over a period of one complete oscillation, there is a definite forward thrust and lift.

"Let us now assume the air to be in such a motion of oscillation due to friction with the earth's surface or to variously moving air masses. By flying through this air in an aircraft with stationary wings the above-mentioned vibration effect would occur. As both forward thrust and lift result, it must be clearly possible to soar in such layers without the help of actual up-wind."

[1] "Aerodonetics," Dr. F. W. Lanchester.
[2] "Ten Years Gliding and Soaring in Germany," Dr. W. Georgii, B.G.A. Journal, No. 1, March, 1930.
[3] "The Development, Design and Construction of Gliders and Sailplanes," Herr A. Lippisch, R.Ae.S. Journal, July, 1931.

Now there are two possible ways of obtaining the conditions necessary for such flight. The first is to fly in a wind with a constant period of gustiness, or wave motion, so that the wing beat effect is obtained on the fixed wings, while the second is to reproduce the fluctuating wind effect by flying backwards and forwards from a wind of a higher velocity to one of a lower velocity.[1]

It is well known that the speed of the wind is lower near the ground, on account of friction, than it is at a higher altitude, so that by continuously diving and climbing the conditions required would be closely simulated.

As the albatross flies across water, the method first mentioned appears to offer the obvious solution, since the wind over the waves must have a certain wave motion, but as these birds at times fly below the tops of the sea waves, or below the region where such air waves would be effective, the second explanation may provide the true solution, or it is even possible that both methods are employed.

[1] A theory partly due to Sir Gilbert Walker, F.R.A., F.R.A.S., M.A. (See "Sailplane," December 17, 1930, and January 2, 1931.)

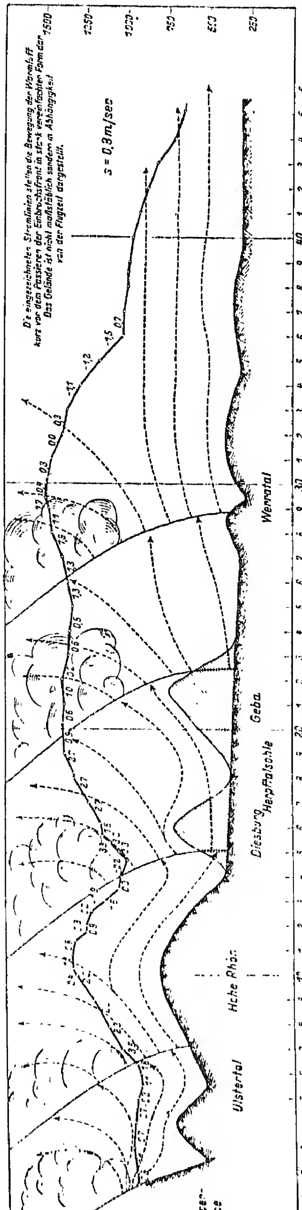


FIG. 167.—Thunderstorm Flight by Hurtigg, August, 1930, over a distance of 32 miles, during which a height of 3,500 feet was attained.

As an explanation of dynamic soaring, Lanchester [1] puts forward the "switch-back" model theory, in which a ball is set rolling on an undulating track, to which is applied a gentle reciprocating movement in the horizontal direction, so that the track moves "with" the ball during descent and "against" the ball during ascent.

It is easily seen that a forward thrust is added during each rise and fall, since the reaction, N, between the track and ball, acts perpendicularly to the track face (see Fig. 168), giving a component in the direction of travel, the path of the ball being inclined at an angle to the track face on account of the horizontal movement added.

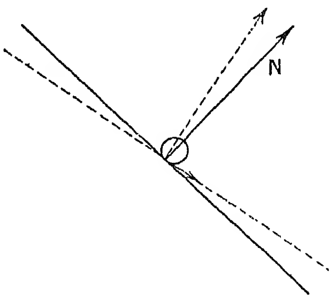


FIG. 168.

The thrust thus supplied may be made sufficient to overcome the small frictional and air resistance and, if the reciprocating motion is increased in intensity, the ball may be made to climb above its starting point, provided the track is so designed to allow this.

The next stage consists of superimposing a uniform movement to the track so that it now moves in one direction only, but with varying velocity. As before, the ball will continue to move along the track.

Now let us replace the track by the air, with a bird or glider, in place of the ball, and follow through the same reasoning.

Consider first the bird flying through a fluctuating wind which blows first against him, decreases to nil and then reverses so as to blow with the bird. This is shown diagrammatically in Fig. 169.

As the wind increases from A to B, the bird climbs, analogous to the ball on the incline, the wing incidence reaching a value equivalent to minimum sinking speed at B, while the speed decreases. At B the gust starts to decrease and a dive is commenced, reaching a maximum velocity as the wind decreases to nil at C.

At this point the bird commences to "flatten out," the

[1] "Aerodonetics," Dr. F. W. Lanchester, para. 153.

process being completed at D, and a following wind has blown up. At D the bird has his maximum speed and is flying at his best gliding angle, and the wind starts to die down again.

The following wind decreasing in intensity is equivalent to a head wind increasing and the bird climbs once more from D to E, sacrificing speed for height.

At E the head wind re-commences, allowing the climb to be continued with a repetition of the process as at A.

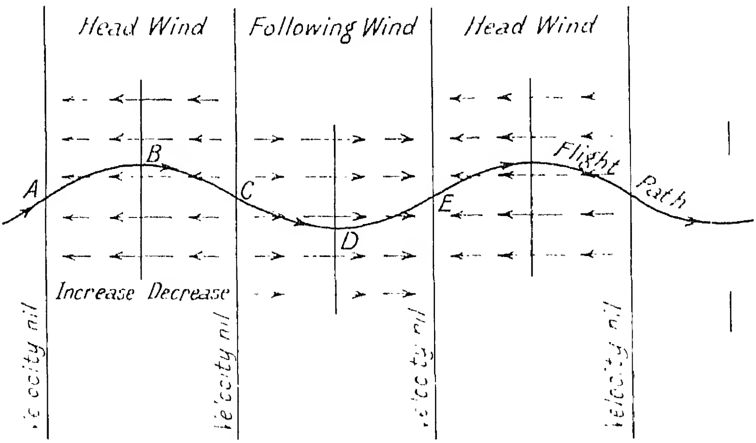


FIG. 160.—Explanatory Diagram of Dynamic Soaring.

There is, therefore, an increase in height or potential energy, as the head wind increases with an increase in momentum, or kinetic energy, as the head wind falls off.

Now retaining these conditions as before, and superimposing a wind in one direction, so that instead of changing direction the wind merely fluctuates between maximum and minimum values, the effect remains unchanged.

Whether the bird flies "with" or "against" the wind makes no difference to the problem, except that when flying "with" the wind he dives as the wind speed increases, whereas "against" the wind the dive takes place as the wind decreases.

Now consider the possible application of this theory to the flight of an albatross. The wind speed is slowed down near the water surface owing to friction, and by continually diving and climbing a bird would be able to reproduce exactly

the conditions described. A high wind is essential for soaring flight by the albatross.

The best height, or stratum, for flight would be that at which the change in wind velocity is most pronounced, and this is likely to be near the surface.

The gliding angle of an albatross is known to be very fine indeed, and its speed is very great (in the neighbourhood of 50 m.p.h.), which means that the rising and falling would not be very marked to an observer.

The two theories put forward in explanation of dynamic soaring are very closely related. In the first the wing beats are reproduced by wave motion of the air, so that the wing passes through alternating regions of up and down moving air, while in the second the air is assumed to be moving backwards and forwards (or equivalent conditions are obtained).

In the former the wing remains perfectly stationary, relative to the earth, apart from its uniform forward velocity, but the effective angle of attack varies continuously, whilst in the latter the angle of the wing is varied to suit the changing velocity of the wind.

CHAPTER XVII

Aero-Towing and Auto-Towing

Towing Aeroplane and Apparatus—The Cable—The Towed Sailplane—Taking Off and Climbing—Aerodynamic Forces Set Up in Towed Flight—Worked Examples—Effect of Speed—Auto-Towing.

Sailplane Towing by Aeroplane

Towing sailplanes by aeroplane, or aero-towing, is used chiefly for enabling the sailplane pilot to reach an initial height quickly and easily, so that he is able to continue soaring in convection currents or with the clouds, or to make contact with a storm in order to make a storm flight. Also the start may be made from flat ground where no hills are available.

Aero-towing also supplies a quick means of transporting sailplanes from place to place.

There is little danger attached to towing by this method, provided that both pilots are skilled and all reasonable precautions are taken, but, in the hands of an incapable aeroplane pilot, or a glider pilot who does not realise the loads that could be imposed on both machines, the chances of disaster are very high.

Towing Aeroplane and Apparatus

The aeroplane to be used for towing should primarily be capable of flying at a low speed. It should be steady in flight and not too powerful. As a speed of about 45 to 50 m.p.h. is considered high enough for most present-day sailplanes, the aeroplane should be able to fly comfortably at this speed with the extra drag of the sailplane.

As the flight is likely to be made not greatly in excess of stalling speed the fitting of slotted wings is a wise precaution.

The towing aeroplane should have a certificate of airworthiness, specially endorsed for towing.

The general form of towing apparatus for fixing to the aeroplane consists of a long rod or tube attached with a univer-

sal joint to the top of a fuselage bulkhead or to the centre section structure, as close to the C.G. position as can be arranged. Suitable strengthening is necessary at this point to ensure that the loads are properly distributed to main members capable of carrying them.

At the rear of the fuselage a guard is built up to keep the towing cable clear of the tail unit, so that fouling is impossible. This consists essentially of a horizontal cross member, on which the towing rod rests, supported on vertical members which attach to the sides of the fuselage. At both ends of the horizontal member are curved uprights, to limit the sideways travel of the towing rod.

The towing cable is attached to the towing rod a short distance behind the tail protection frame, there being a quick release incorporated, actuated from the pilot's cockpit, so that the glider can be slipped, in the event of an emergency, and also so that the cable may be dropped before landing.

A simple alternative, to the guard described, is to attach a stout ring to the top of the fin-post, through which the towing cable is passed. Care should be taken to ensure that the sternpost is capable of standing the loads to which it will be subjected.

The Cable

The cable should be of the extra flexible type, with a breaking load approximately equal to the all-up weight of the glider, or, better still, should include a weak link of this strength. This link should be inserted between the glider and the cable. (The reason for the weak link is explained later.)

The length of cable depends on the weather conditions, but should not be less than 300 ft. During gusty or "bumpy" conditions a length of 500 or 600 ft. should be used, as with the greater length unsteady movements of one machine are not so readily transmitted to the other. The shorter cable enables a quicker climb to be made, under calm conditions.

Air Ministry regulations state that the cable should be dropped only at licensed aerodromes, from a height not exceeding 300 ft., and that permission should first be obtained.

The Towed Sailplane

A sailplane in towed flight is subjected to different loadings

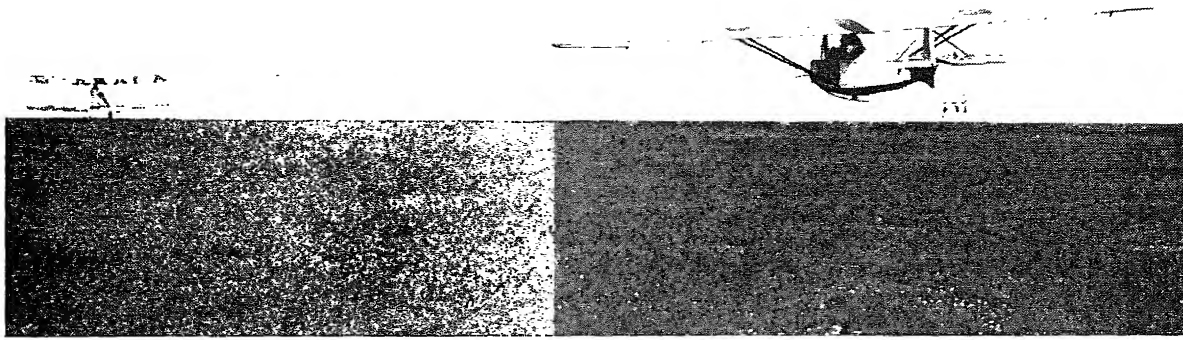


Fig. 17.—Towed Sailplane Taking-off.

[To face page 208.

from those obtaining in normal gliding and soaring flight. For instance, the speed may be far higher, the climb steeper, and the weight supported may be considerably greater, as the sailplane can be made to carry a portion of the weight of the towing machine. There may also be a drag force of some magnitude to be considered.

Unless a sailplane has been specially designed for towed work, the strength should be checked before any such flights are made.

If the main planes, forward of the main spar, are covered with plywood, this will materially help as regards the drag loads, providing the plywood joints are well made, but some form of exterior bracing may be necessary. Without this covering a careful check of the drag bracing system should be made.

In high speed flight, C.P.B., the ply nose is subjected to torsion loads as well as the drag forces.

Sailplanes used for towing purposes are generally supplied with some form of wheel landing gear to reduce the friction during the start, and so expedite the take-off. A quick release, of simple and foolproof pattern, and operable by the pilot, should be fitted at the cable attachment. The attachment is generally either at the nose, or further back, underneath the fuselage, to come closer to the C.G. position.

Taking-off and Climbing

The start should be made directly into wind on a large flat aerodrome, the sailplane being placed close up to the boundary, in order to ensure as long a run as possible. The cable is stretched between the aeroplane and the sailplane before the start.

As the acceleration is somewhat slow, it is advisable to post assistants at each wing-tip to run forward with the sailplane until sufficient speed is reached for the lateral control to become effective.

On a signal from the sailplane pilot, to the effect that all is ready, the aeroplane pilot opens his throttle gradually, to ensure even acceleration, and both machines move off across the aerodrome.

As the speed reaches the minimum for the glider, at its angle of take-off, say, 28 m.p.h., the glider leaves the ground and climbs slowly until it takes up a position in which the

cable makes an angle of 15° or 20° with the horizontal. Actually the glider leaves the ground after a very short run, owing to the slipstream from the aeroplane propeller.

The aeroplane speed continues to increase, till it reaches the minimum for take-off, say, 40 m.p.h., when it also leaves the ground and climbs very slowly. The take-off speed of the aeroplane is slightly higher when towing than when free, owing to the increased resistance.

On attaining a speed of a few miles per hour in excess of stalling, perhaps 45 m.p.h., the throttle is eased off slightly, so as to retain a constant speed of this amount.

A steady climb is thus made with the sailplane a little higher than the aeroplane throughout, so as to avoid the slipstream.

No turn should be made unless the radius is very large, and any jerky movement on the part of the sailplane might cause the towing machine to stall.

If the atmospheric conditions are not calm, both machines will tend to rise and fall, with consequent jerking of the connecting cable. This will be noticed least when the cable is long.

The glider pilot should take care to remain above the aeroplane slipstream, or severe buffeting may be experienced, when within the slipstream region, and if the glider falls below the aeroplane, it is difficult to regain height. It should be remembered that the slipstream is being driven backwards, so that the air speed of the sailplane when in this region will be that of the aeroplane plus the slipstream velocity. The change in velocity when entering or leaving the slipstream has a noticeable effect, added to which the helical motion of the air has to be contended with.

The pilot of the sailplane should concentrate on keeping the cable just taut and not allow it to droop. If the cable should tend to sag the slack should be taken up by a gentle turn to one side, after which the correct position can be carefully regained. From this it follows that any excess height of the sailplane over the towing machine should not be lost by diving but by working from side to side in order to increase the length of path flown by the glider.

Aerodynamic Forces Set up in Towed Flight

The forces set up in steady flight, both on the sailplane and on the towing aeroplane, depend on the speed of flight,

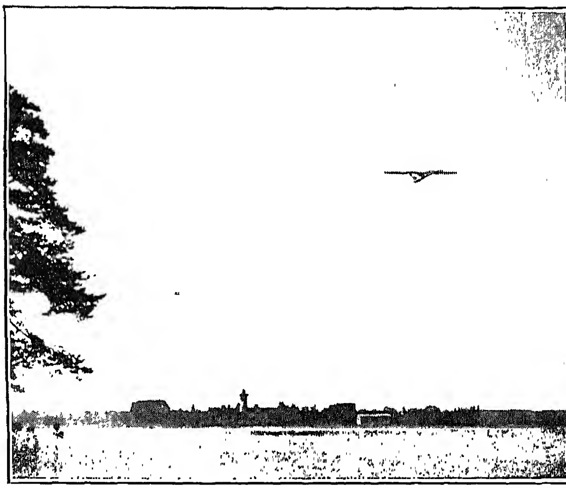


FIG. 171.—Sailplane in Towed Flight.

[To face page 210.

the position of the glider relative to the towing machine; the cable attachment position on the glider relative to its C.G., and other factors.

In any one position of the sailplane relative to the aeroplane there may be two possible attitudes for the sailplane, one at a small angle of attack, and the other at a coarse angle, but either the engine power or the velocity would have to be varied. It should be noted that any change of attitude or position of the sailplane has an immediate effect on the aeroplane, both lift and drag being altered with a corresponding alteration in the aeroplane's speed.

If the sailplane is above the aeroplane, then it must support some part of the latter's weight, but, if below, this condition is reversed. It may be noted that it might be possible to obtain a reversal of loading on the sailplane main planes, if the sailplane were below the aeroplane and had the elevators hard down, so as to cause an upward load on the tail. This condition is hardly likely to take place.

There are two cases to be considered, neglecting the case in which the glider is below the aeroplane, already mentioned.

Case 1. Glider Directly Behind Aeroplane.—This is equivalent to flight with power, in which the pull in the cable, P, is equal to the drag of the glider: and the air reaction on the wings, $R=\sqrt{W^2+P^2}$.

For moderate speeds P will be quite small.

There may be a small turning moment tending to make the machine climb or dive, if the cable is attached below or above the C.G. of the glider, but this would be compensated by means of the elevator.

This case is not serious, and is not likely to approach the pull in an elastic cable during the normal hand launch, for which all sailplanes are designed.

Case 2. Glider Above Aeroplane.—Assuming the main forces all act through the C.G., by reference to Fig. 176

$$R \sin\theta = P \cos\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{and } R \cos\theta = P \sin\phi + W \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If, however, the line, through which the cable pull acts, does not pass through the C.G. position, there must be a compensating load on the tail, P_T. (See Fig. 177 on page 214.) There may also be a couple, due to the main plane resultant not

passing through the C.G., depending on the C.P. position, and this may assist the tail load in overcoming the cable pull moment, or it may act against the tail load.

Under these conditions the formula (2) given above becomes

$$R \cos \theta = P \sin \phi + W + P_T \quad . \quad . \quad . \quad . \quad . \quad (3)$$

It should be noted that the tail load may not be vertical, but inclined forwards to some extent, in which case $P_T \cos \epsilon$ should be inserted for P_T, and $P_T \sin \epsilon$ should be added to $R \sin \theta$ in (1).

There is a third equation for equilibrium—

$$P\,d_1 + R\,d_2 = P_T\,d_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where d_1, d_2 and d_3 are the perpendicular distances from the C.G. to the line of action of the various forces.

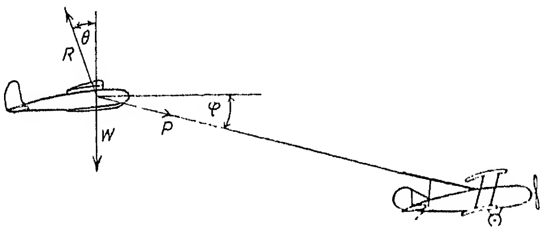


FIG. 172.—Forces set up in Aero-towing.

The worst cases of loading are likely to take place when the sailplane attains its maximum height above the aeroplane, and in order to determine the maximum cable strength to prevent over-loading of the sailplane, some examples will be given in which average values are assumed for what would be known quantities for any one particular design.

Assumptions: Sailplane weight, W=500 lbs., wing area, 200 sq. ft., weight=200 lbs., factor of loading for main planes=6, tail area=20 sq. ft., tail plane C.P. to C.G.=12 ft. Other assumptions will be made as necessary, and speed will be taken as uniform at 45 m.p.h. =66 ft./sec.

To simplify the calculation, θ will be assumed to equal α, the angle of attack. This is nearly correct.

Also calculations will be based on the stipulation that the wing strength shall retain a factor of safety of at least 2 at all times.

Example I. *Angle of Attack Maximum, Cable Attachment at C.G.*— *Assume* $\theta = \alpha = 16°$.

From (1) $R \sin \theta = P \cos \phi$.

Now, for safety, R should not exceed half the designed wing load, or $R = \frac{300 \times 6 + 200}{2} = 1{,}000$ lbs.

The added 200 lbs. is the wing weight. It should be pointed out that the wing reaction must be 200 lbs. to support the weight of the wing structure, to which must be added the designed load of 300 lbs., with a factor 6.

Then $.2756 \times 1000 = P \cos \phi$

and $P \cos \phi = 275.6$ lbs.

This is the total drag of the glider under these conditions, and thrust horse-power of the aeroplane, absorbed in overcoming this drag, will be $\frac{DV}{550} = \frac{275.6 \times 66}{550} = 33$ h.p.

From (2) $.9613 \times 1000 = 500 + P \sin \phi$

or $P \sin \phi = 461.3$ lbs.

These two equations give $\tan \phi = \frac{461.3}{275.6} = 1.67$

and ϕ, the angle of cable, $= 59°$, say.

Then P, the pull in cable, $= \frac{275 \cdot 6}{.515} = 545$ *lbs*.

The cable strength should not exceed this, or should include a weak link to fail at this load.

Check.—If the drag is 275.6 lbs. $V = 66$ ft./sec.

Then $K_D = \frac{275.6}{.0024 \times 200 \times (66)^2} = 0.132$

This appears about right for flight at maximum incidence. The wing drag will be approximately $.0024 \times .07 \times 200 \times (66)^2 = 146$ lbs., and the wing structure should be capable of taking this.

Example 2. *Conditions as before, but Cable Attachment at Nose*.—

Inserting the values in the equation given

$275.6 = P \cos \phi$ . . . . (1)

$961.3 = P \sin \phi + 500 + P_T$ . . . . . . (3)

and $P d_1 + R d_2 = P_T d_3$ . . . . (4)

Now, at maximum incidence, the centre of pressure is forward, and d_2 will be nil, or very little, so that this term can be neglected. At other angles of attack, d_2 would be obtained from the wing section, together with a general arrangement drawing of the sailplane, and presents no difficulty.

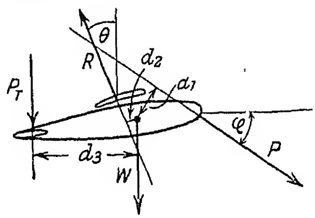


FIG. 173.—Forces on Sailplane in Aero-towing.

The height above the aeroplane to which the sailplane can climb will be determined by the tail force available at the particular speed, as the tail moment has to overcome the diving moment caused by the cable pull at the nose.

The tail force will be $P_T = .0024 \times 20 \times .5 \times (66)^2$,
$= 104$ lbs.,

assuming a value of $K_L = 0.5$ for the tail plane and elevator, and therefore $104 \times 12 = P\ d_1$ from (4).

From (3) $961.3 = P \sin \phi + 500 + 104$
or $P \sin \phi = 357.3$

Dividing by (1) $\tan \phi = \frac{357.3}{275.6} = 1.294$ and $\phi = 52° 20'$, say,

and $P = \frac{375}{.7916} = 452$ lbs., and from (4) $d_1 = \frac{1248}{452} = 2.77$ *ft.*

The sailplane, at the angle of attack, should be drawn out, together with the cable at the angle found, and the distance, d_1, checked.

If d_1 as measured is found to be greater than the calculated value, then the tail plane is not sufficiently powerful to enable the machine to reach such a height.

The value of 2.77 ft. obtained seems quite reasonable.

The cable strengths necessary for the two examples considered were 545 and 452 lbs., from which it would appear that a fair criterion for the cable strength would be that it should not exceed the loaded weight of the glider, as stated on page 208. This is, of course, only general, and would not apply in all cases.

On the other hand, too weak a cable might result in a breakage during the take-off, with serious results. The minimum strength necessary depends largely on the frictional

resistance between the glider and the ground and the acceleration at the start.

A cable strength of less than half the total glider weight, or, say, 250 lbs., is not recommended.

It may be interesting to compare the cable loads already calculated with the load during normal flight with the glider only just above the aeroplane.

Example 3. *Conditions as before, but with a* 300 *ft. cable. Sailplane height above aeroplane about* 75 *ft., making an angle* $\phi = 15°$ *approximately with the horizontal.*

The line of cable pull will pass through, or very close to, the C.G., and its moment may be neglected.

$R \sin \theta = P \cos \phi = .9659$ P.

Now R is dependent on θ, and values are required which will close the polygon of forces.

The weight, W = 500 lbs., is set off vertically in a force diagram, and the direction of the cable pull at 15° above the horizontal. (See Fig. 174.)

Values of $R = .0024 \times 200 \times (66)^2 \times K_R$ are calculated for several values of α, keeping the velocity constant at 66 ft./sec., and the curve is then plotted on the diagram by setting out the values of R for the angles calculated. The intersection of this curve with the cable line gives the required value, in this case—3°, for an angle, $\theta = 30'$ and K_R for the wing section used, $= 0.245$, giving R = 512 lbs.

Hence $.9659\ P = 512 \times .1305$, and

$P = 69.25$ lbs.

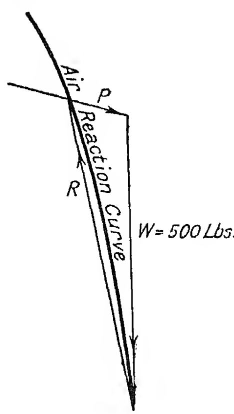


FIG. 174.

It should be noted that the values of K_R and α should be for the aerofoil section at the aspect ratio employed.

Effect of Speed

So far all calculations have been based on a towing speed of 45 m.p.h., which at the present time is considered a reasonable value.

An increased speed will result in much greater air reaction on the main planes, but provided that a weak link is included

in the cable, to prevent overloading, there should be no danger.

As the speed increases, so will the maximum permissible cable angle decrease, unless there is a corresponding increase in the factors of design.

(See Appendix V for the B.G.A. Regulations for Aero-towing.)

Auto-Towing

Auto-towing, or towing by motor car, resembles aero-towing to a large extent, and much of what has been written for aero-towing applies here also.

Auto-towing is used chiefly for instructional purposes, but where a sufficiently large aerodrome or unobstructed level ground can be obtained it is possible to gain sufficient height to enable soaring flight to be continued with convection or cloud currents. It is also used, either from the top or from the base of a hill, as a method of launching for contour soaring. These remarks refer also to towing behind motor-boats, as the conditions are very similar.

A long cable should be employed, of about 300 ft. in length, and of extra flexible construction. The conditions of loading are not dissimilar to those obtaining with aero-towing and a cable strength not greater than the loaded weight of the sail-plane, and not less than half, is recommended. A stronger cable may be used provided that slower flying speeds are maintained.

In order to gain height quickly the sailplane is made to climb steeply immediately following the take-off, and may reach a height of 500 ft. in 30 seconds. This means that the path of the glider is longer than that of the car and consequently the speed is greater. For this reason the car speed may be slightly decreased after the take-off.

Quick release devices should be fitted at both ends of the cable.

The car speed may be accelerated to the maximum velocity quite quickly, but both acceleration and velocity should be uniform, and no gear change should be made after the glider leaves the ground. A powerful car is essential, and it should be fitted with chains if the ground is wet or slippery.

The car should be driven on a straight course directly into wind, the wind speed being ascertained before each flight

and deducted from the required speed to obtain the speed at which the car should be driven. This is most important, especially in a high wind, and is one of the main points of difference between auto- and aero-towing. An air speed indicator fitted to the towing car is a great advantage.

The sailplane should be fitted with a wheeled landing chassis. Two wheels are better than one, as lateral balance can be more easily retained during the intervening period from the start to the time when the glider becomes air borne. If one wheel is used, wing-tip skids are beneficial.

Great care is needed during the period from the actual take-off to the attainment of a height of about 30 ft., as a loss of flying speed, for any reason whatever, must cause a stall, accompanied very likely with serious results. A frayed or kinked cable may lead to fracture during flight, in which case the sailplane is left in a climbing attitude, without thrust to support it, and a spin is almost inevitable.

For the same reason the sailplane should be put into a gentle dive before releasing the cable, after the required height has been attained.

The car driver, or his assistant, should keep a watch on the glider during the whole time it is attached, and by accelerating or slowing down can often help to avoid difficult circumstances.

The B.G.A. Regulations for Auto-Towing are given in Appendix IV.

CHAPTER XVIII

Flying Instruments

Air Speed Indicators—The Altimeter—The Variometer—The Compass—The Barograph.

Air Speed Indicators

A sensitive air speed indicator is the most useful instrument. Sailplane pilots are taught to rely mainly on " feel " for flying speed, but for the best performance an indicator is necessary.

The speed at which maximum height can be obtained in an up-current is only a few miles per hour greater than stalling speed, and the difference between this and a mile or two faster or slower has not only an effect on the height attainable, but also on the time taken to reach any particular altitude.

There are other optimum speeds of flight, such as for best gliding angle in calm air and when flying against or with a wind, for which conditions the speed indicator is a great asset.

There are several types of air speed indicators, or anemometers, but these can be divided into three main categories, viz. the tube anemometer, the rotating cup, and the flat pressure plate. The tube anemometer is the type most generally used in this country, and consists of two parallel tubes facing directly forward on the machine. The lower, called the pitot tube, is open-ended, while the other, or static tube, is closed at the end, but has a series of small holes drilled round the circumference.

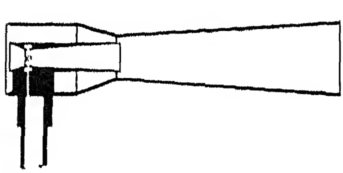


Fig. 175.
Venturi Anemometer.

The tubes lead to the recording instrument and connect on either side of a diaphragm, so

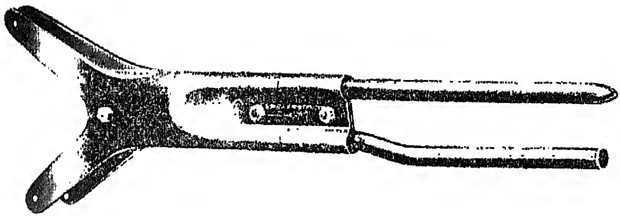


FIG. 176.—Pitot and Static Tubes.

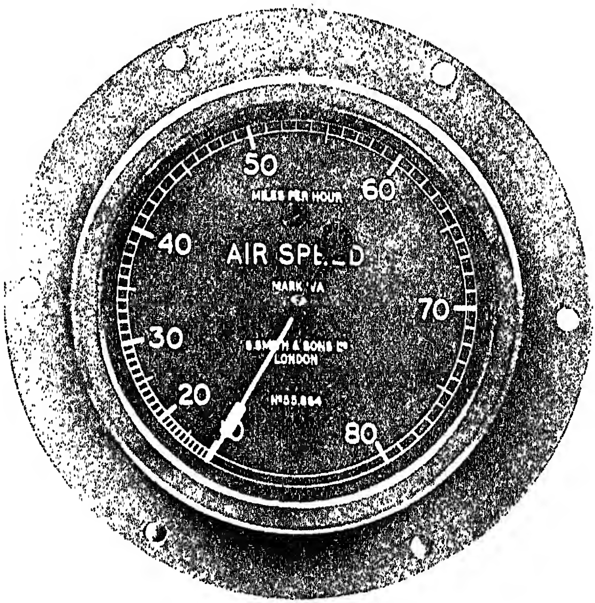


FIG. 177.—Air Speed Indicator.

[To face page 218.

that the diaphragm moves according to the pressure difference in the two tubes.

The pitot-head should be fixed to the sailplane well clear of all possible disturbing influences, and at least 18 in. in front the part it attaches to. The front of a fuselage and the wing leading edge are not very satisfactory on account of the deflection of the air flow over those parts.

In order to increase the amount of sensitivity of the tube anemometer, a venturi tube is fitted in place of the static head, which thus produces a suction.

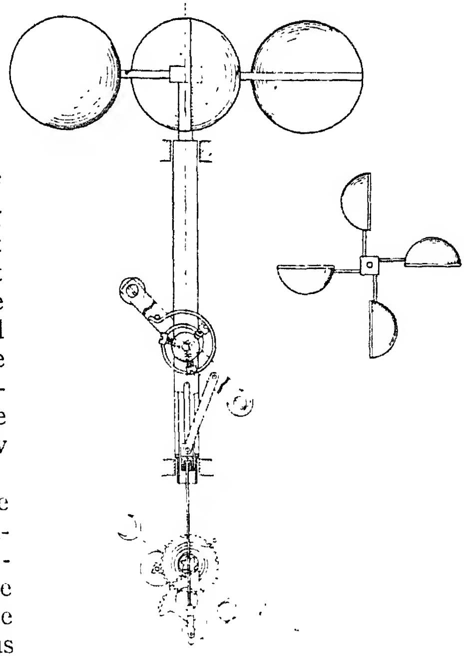


Fig. 178.
Mechanism of Rotating Cup Anemometer.

The rotating cup anemometer is used considerably in Germany. Four semi-spherical cups are mounted on a vertical spindle to which small weights are hinged.

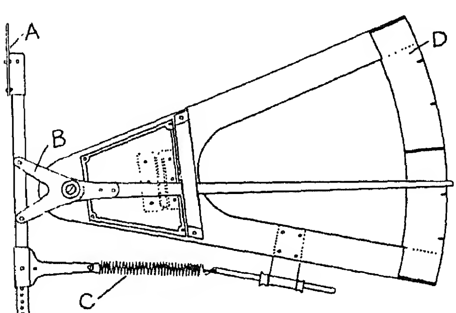


Fig. 179.—Pressure Plate Anemometer.

As the cups rotate the weights are thrown outwards by centrifugal force against restraining springs, the amount of movement being registered on a dial.

The pressure plate type consists of a single plate exposed to the air so that the speed of flight causes the plate

to lift against a restraining spring, the amount of lift depending on the speed. This is a very simple type, but is not much used.

The Altimeter

The next instrument of importance is the altimeter. This should be sensitive and with the minimum of lag. The height for starting a distance flight can be gauged by this, and also if a knowledge of the country is possessed by a pilot he can judge, by his height, the possibility of reaching various sources of up-currents for the continuation of a flight.

Altimeters are built on the aneroid barometer principle, and consist essentially of a thin round air-tight metal box, with corrugated ribs, from which the air has been exhausted.

The box is made of very thin material, so that the sides resemble diaphragms and deflect according to the air pressure on the outside.

By measuring the air pressure the height above the earth's surface is obtained.

The Variometer

The variometer is of great value, as it indicates to the pilot whether the machine is rising or sinking, or, in other words, it denotes the presence of vertically moving air, when the movement is of slight intensity.

Unfortunately, most variometers possess a certain amount of lag which limits their usefulness to some extent.

The variometer consists of an air chamber fitted with a diaphragm which is exposed on the outside to the atmosphere. Air is trapped inside the chamber, which when taken to a higher or lower level causes the diaphragm to move outwards or inwards on account of the difference in pressure.

The air chamber is connected with the outside by a long tube of fine diameter, so that air flows inwards or outwards but with restricted flow, this being known as the capillary leak principle.

The Compass

This is too well known in principle to need explanation here. Sailplane compasses are made of 2 or 3 in. diameter and of very small weight.

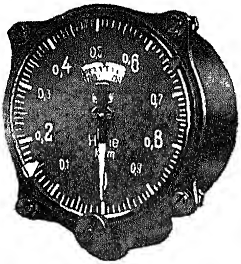


Fig. 180. Altimeter (Askania).

Fig. 181.—Sailplane Compass (Askania).

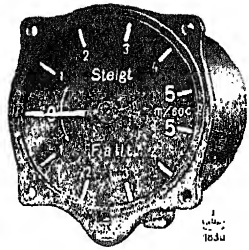


Fig. 182.—The Variometer.

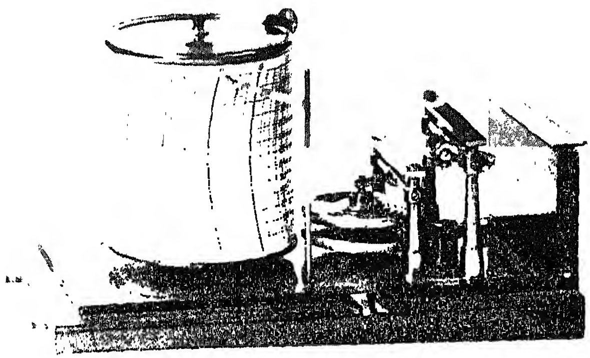


Fig. 183.—The Barograph (Smith's Instruments).

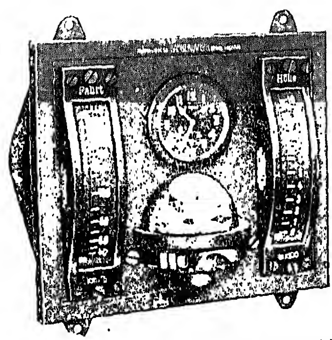


Fig. 184.—Sailplane Instrument Panel (Askania).

[*To face page 220.*

Their accuracy is not of such importance, as for power aeroplanes, since flights by compass course are not usual.

A compass is necessary for distance flying and is of assistance when flying in clouds or mist.

The Barograph

The barograph is required for most competition events and work of an experimental nature. The height during the whole course is recorded in a permanent form and shows clearly the intensity of upward and downward moving air streams encountered during a flight.

The principle of the barograph is similar to the altimeter, the height being measured by the difference in pressure on the outside of a thin metallic box exhausted of air.

The expansion and contraction of the box causes a lever arm, fitted with a pen, to move over a prepared chart and thus record the height against time.

The recording paper or drum is rotated by means of a clock.

APPENDICES

APPENDIX I

Theory of Induced Drag

Fig. 185 represents the air flow past an aerofoil section so that it is deflected through an angle, ϵ, from the horizontal. The mean direction of the air stream is shown by the dotted line AA.

The air reaction is divided normally into components, perpendicular and parallel to, the initial wind direction shown by L and D, but, if the line AA is used as datum, then the components become L_p and D_p, which are called profile lift and profile drag, respectively.

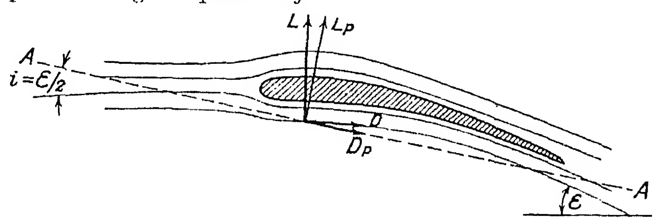


Fig. 185. Diagram illustrating Induced Drag.

L and L_p are substantially equal, since the component of D_p parallel to L is negligible in comparison, and, consequently, the lift values will not be considered further.

The drag values are not, however, equal in magnitude, as the component of L_p parallel to the drag axis is considerable in relation to D.

The drag may now be considered as made up of two parts, the true or profile drag and a component of the lift called "induced drag," and it is the value of this that varies with and is dependent on aspect ratio.

Induced Drag Component

Roughly speaking, the downward momentum imparted to the air by the presence of the aerofoil, in unit time, is equal to

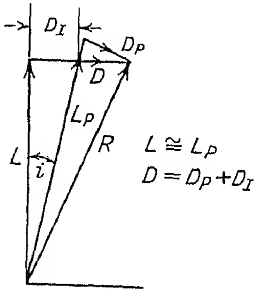


FIG. 186.

the mass of air acted on, multiplied by the downward velocity, which, in turn, is equal to the speed of air flow, V, times *sin* ϵ, where ϵ is the angle through which the streamlines are deflected.

If A^1 is the area of the affected air, then the downward momentum must equal $A^1.V^2.\epsilon.\rho/g$, ϵ being in radians, and, since this must equal the vertical reaction on the aerofoil, we get

$$L = A^1.V^2.\epsilon.\rho/g. \qquad (1)$$

The mean wind angle or angle of induced drag, as it is termed, $i = \epsilon/_2$, hence

$$i = \frac{L}{2.A^1.V^2.\rho/g.} \qquad (2)$$

By Prandtl, the equivalent area, within which the wing may be assumed to affect the air flow, approximates to a circle, with diameter equal to the wing span.

$$\text{Hence } A^1 = \frac{\pi\ S^2}{4} \qquad (3)$$

where S = span.

The induced drag, by Fig. 186, may be taken as the lift multiplied by the relative wind angle or

$$D_I = L \times i, \text{ but } i = \frac{L}{2.A^1.V^2.\rho/g}, \text{ from (2)}$$

and substituting the value of (3) for A^1, we get

$$D_I = \frac{L^2}{\pi.S^2.V^2.\rho/2g.} \qquad (4)$$

Inserting coefficients, in place of the forces so far used we get from the normal form of drag equation :

$$K_{DI} = \frac{D_I}{A.V^2.\rho/g.} \text{ and giving } D_I \text{ the value of equation (4)}$$

$$= \frac{L^2}{\pi.S^2.V^2.\rho/2g. \times A.V^2.\rho/g.}$$

$$= \frac{L^2}{\pi.S^2.A.V^3.\rho^2/2g^2.}$$

Now $L = K_L.A.V^2.\rho/g.$

Therefore $K_{DI} = \dfrac{(K_L.A.V^2.)^2.\rho/g.}{\pi.S^2.A.V^4.\rho^2/2g^2.}$

$$= \frac{K_L^2.A.}{S^2.\pi/_2} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

and since S^2/A = aspect ratio, or Λ,

$$K_{DI} = \frac{K_L^2}{\Lambda.\pi/2} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

and this gives the coefficient of induced drag in terms of K_L, and the aspect ratio.

Effect of Change of Aspect Ratio on Angle of Attack

An increase in aspect ratio gives higher values of L /D, owing to the fact that the lift coefficient values are produced at smaller angles of attack. This decrease takes place in the induced angle of attack, as it is the induced drag component that is reduced, and it is necessary, therefore, to find the value of the induced angle.

The difference between the values of the induced angles of attack, for two different aspect ratios, is deducted from the angle for the life coefficient being considered, in order to find the angle of attack for the higher aspect ratio producing the same lift value.

From (2) $i = \dfrac{L}{2\,A^1.\,V^2.\,\rho/g.}$

and substituting again the normal value of L, and $\dfrac{\pi S^2}{4}$ for A^1—

$$i = \frac{K_L.\ A.\ V^2.\ \rho/g.}{2.\ S^2\ V^2\ \rho./g.\ \pi/4} = \frac{K_L.\ A}{S^2\ \pi/_2.}$$

$= \dfrac{K_L}{\Lambda\ \pi/2.}$ in terms of the lift coefficient and aspect ratio.

Changing i from radians to degrees

$$i = \frac{57{\cdot}3\ K_L}{\Lambda\pi/_2.} = \frac{36.5\ K_L}{\Lambda} \qquad . \quad . \quad . \quad . \quad . \qquad (7)$$

The change in the angle of attack, then, for an alteration of aspect ratio is given by

$$a_2 = a_1 - (i_1 - i_2), \text{ or}$$

$$a_1 - a_2 = 36.5\left(\frac{1}{\Lambda_1} - \frac{1}{\Lambda_2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where a_1 and a_2 are the angles of attack for the aspect ratio at which the aerofoil was tested, Λ_1, and for the new value for the design, Λ_2, respectively.

APPENDIX Ia

Method of Obtaining Polar of Aerofoil for Aspect Ratios other than that for which Test Results are Available

In sailplane design it is necessary to use the polar curve of the aerofoil characteristics relating to the particular aspect ratio that is being used for the design, Λ_2, and as test results are generally available for one aspect ratio only, Λ_1 (usually 5 or 6), it becomes necessary to calculate values of the modified polar.

Fig. 19 on page 35 shows the polar of Göttingen 535 section, for an aspect ratio of 5, which has been prepared from the wind tunnel test results.

Since the portion of the drag known as profile drag remains constant for all aspect ratios for any one wing section, it is possible to find the values over a series of angles of attack, by first calculating the coefficient of induced drag for the aspect ratio of the test and then subtracting this from the total drag coefficient.

The coefficient of induced drag for the new aspect ratio can then be calculated, and added to the profile drag, thus obtained, to give the total drag at the aspect ratio required.

As an example, calculations are shown for section Göttingen 535, and a change of aspect ratio from 5 to 15, the results being tabulated in tables 5 and 6.

In Table 5, $K_{DI} = \dfrac{K_L^2}{\pi/_2 \cdot \Lambda}$ from formula (6), Appendix I.

Hence for ratio 5, $K_{DI} = \dfrac{K_L^2}{\pi/_2 \times 5} = .1274\ K_L^2.$

Hence values of K_{DI} are found.

K_{DP} is then obtained by subtracting K_{DI} from K_D.

In Table 6 the values of K_{DI} are calculated for the new aspect ratio, and added to the profile drag figures of Table 5, giving the drag coefficient for the required ratio.

The values of the angle of attack have not been included in the second table, since they will be changed from the values in the first table. If the angles are required, they may be calculated as shown previously, Formula 8, Appendix I.

The new drag values may now be plotted as abscissæ, against the lift values as ordinates, and this is done in Fig. 19 previously referred to.

The values for induced drag have also been plotted for this aspect ratio, the difference, horizontally, between the induced drag curve and the polar, for aspect ratio 15, being the profile drag. It will be noticed that the profile drag remains fairly constant at all angles, whereas the induced drag component increases rapidly as the angle of attack increases.

Since high angles of attack are important with sailplane work, the value of low induced drag, and consequent high aspect ratios, is readily appreciated, whereas with high speed aircraft, using low values of angle of attack, the need for large aspect ratios is not so apparent.

TABLE 5

PROFILE DRAG, GÖTTINGEN 535

$\alpha°$	K_L	K_L^2	$K_{DI} = \frac{K_L^2}{\pi/_2 A}$	K_D	$K_{DP} = K_D - K_{DI}$
−8	0.02	.0004	.000051	.009	(.009)
−4	0.16	.0256	.00326	.01	.0067
0	0.315	.0991	.01262	.02	.0074
4	0.46	.212	.0270	.035	.0080
8	0.6	.36	.04585	.0545	.0086
12	0.715	.51	.0650	.08	.0150
16	0.78	.61	.0777	.11	.0323

TABLE 6

DRAG COEFFICIENTS FOR ASPECT RATIO 15

K_L	K_L^2	$K_{DI} = \frac{K_L^2}{\pi/_2 \Lambda}$	K_{DP} (from Table 5)	$K_D = K_{DI} + K_{DP}$
0.02	.0004	—	(.009)	.009
0.16	.0256	.00107	.0067	.00777
0.315	.0991	.00418	.0074	.01158
0.46	.212	.00905	.0080	.01705
0.60	.36	.01528	.0086	.02388
0.715	.51	.0217	.0150	.0367
0.78	.61	.0259	.0323	.0582

AEROFOIL R.A.F. 30.*

Size of Model ... ... Span 48 in., Chord 8 in.
Reynolds No. ... ... Vc/v = 335,500 and 252,000.
Wind Tunnel ... ... R.A.E. 7 × 7 ft.
Year of Test ... ... 1924.

PROFILE.
(Symmetrical Section.)
(Co-ordinates are per cent. of chord.)

Distance from L.E.	Upper and Lower Surfaces.
0	0
1.25	1.80
2.5	2.48
5	3.46
10	4.68
15	5.44
20	5.94
25	6.20
30	6.32
35	6.30
40	6.20
45	6.00
50	5.66
55	5.26
60	4.78
65	4.28
70	3.70
75	3.12
80	2.50
85	1.90
90	1.30
95	0.70
100	0

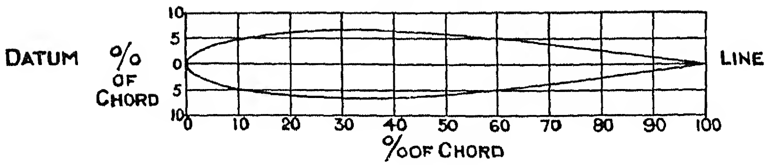
Radius of Curvature at *L.E.* = 1.29 per cent. chord.
Radius of Curvature at *T.E.* = 0.13 per cent. chord.

COEFFICIENTS.
Values relate to aspect ratio 6 and are corrected for tunnel interference.

$\alpha°$	K_L	K_D	K_{CP}	K_M	$K_L/_D$
(Vc/v = 335,500.)					
—0.9	—0.031	—	—	—	—
+0.2	+0.007	0.0050	—	—	1.4
2.3	0.083	0.0058	—	—	14.3
4.3	0.156	0.0081	—	—	19.3
6.4	0.231	0.0120	—	—	19.3
8.4	0.306	0.0174	—	—	17.6
10.4	0.372	0.0235	—	—	15.8
12.4	0.429	0.0312	—	—	13.7
14.3	0.458	—	—	—	—
16.0	0.365	—	—	—	—
17.9	0.353	—	—	—	—
(Vc/v = 252,000.)					
—1.8	—0.069	0.0062	—	+0.0125	—
+0.05	+0.003	0.0056	0.935	—0.0033	0.5
0.2	—	0.0054	—	—	—
2.1	0.075	0.0062	0.259	—0.0194	12.1
4.1	0.144	0.0084	0.240	—0.0346	17.2
6.1	0.222	0.0122	0.245	—0.0543	18.2
8.1	0.300	0.0176	0.250	—0.0748	17.0
10.0	0.360	0.0236	0.242	—0.0920	15.3
12.0	0.415	0.0309	0.240	—0.0991	13.4
13.8	0.402	—	0.284	—0.1156	—
15.6	0.362	—	—	—	—

* R. & M. 928.

RAF 30



AEROFOIL R.A.F. 30.

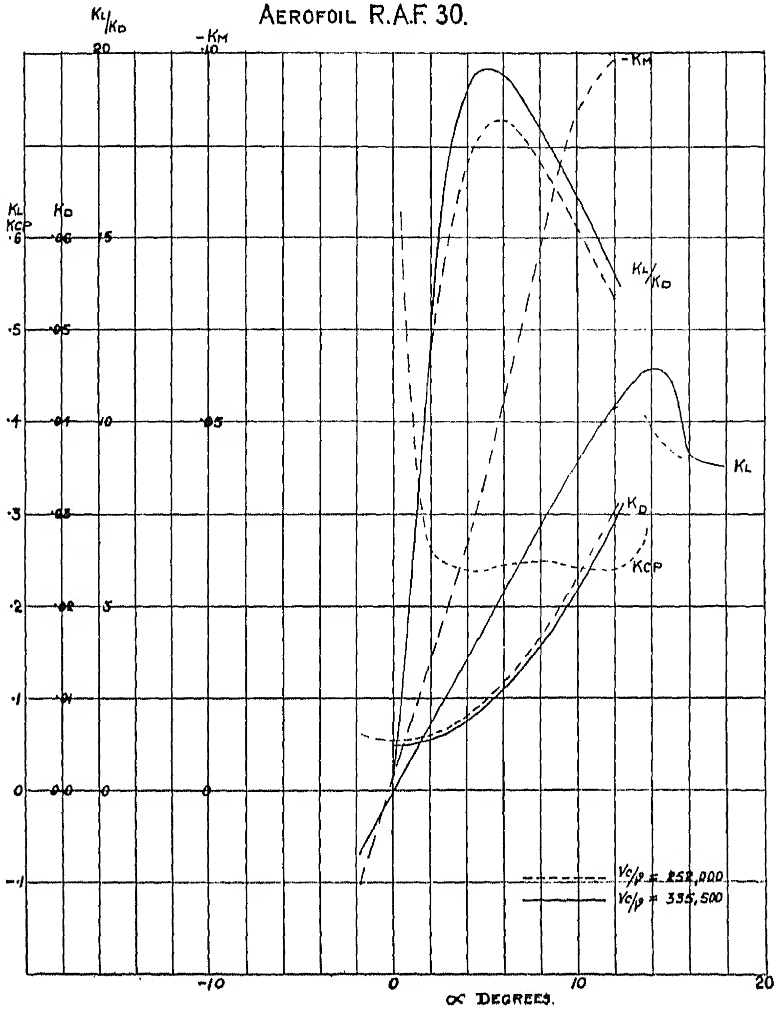


FIG. 187.

AEROFOIL R.A.F. 34.*

Size of Model	... ...	Span 48 in., Chord 8 in.
Reynolds No.	... ...	$Vc/v = 335{,}500$.
Wind Tunnel	... ...	R.A.E. 7×7 ft.
Year of Test	... ...	1926.

Profile.

(Co-ordinates are per cent. of chord.)

Distance from L.E.	Upper Surface.	Lower Surface.
0	0	0
1.25	1.98	—1.62
2.5	2.82	—2.14
5	4.11	—2.81
10	5.83	—3.53
15	6.97	—3.91
20	7.72	—4.16
25	8.14	—4.26
30	8.32	—4.32
35	8.27	—4.33
40	8.08	—4.32
45	7.74	—4.26
50	7.21	—4.11
55	6.59	—3.93
60	5.87	—3.69
65	5.13	—3.43
70	4.31	—3.09
75	3.49	—2.71
80	2.70	—2.30
85	1.95	—1.85
90	1.26	—1.34
95	0.64	—0.76
100	0	0

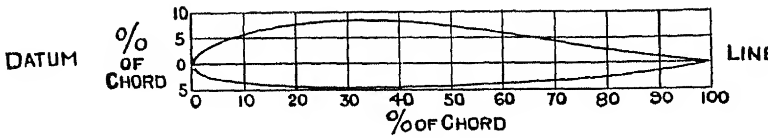
Coefficients.

Values relate to aspect ratio 6 and are corrected for tunnel interference.

$a°$	K_L	K_D	K_{CP}	K_M	K_L/K_D
—1.2	—0.0035	0.0056	—1.34	—0.0048	—0.6
+0.9	+0.070	0.0055	+0.275	—0.0193	+12.7
2.9	0.157	0.0078	0.262	—0.0411	20.1
5.0	0.244	0.0124	0.268	—0.0655	19.7
7.1	0.328	0.0180	0.266	—0.0871	18.2
9.1	0.395	0.0244	0.260	—0.1023	16.2
11.2	0.452	0.0320	0.253	—0.1134	14.1
13.2	0.494	0.0410	0.250	—0.1227	12.0
15.2	0.510	0.0546	0.258	—0.1302	9.4
17.2	0.499	—	—	—	—
19.2	0.456	—	—	—	—

* R. & M. 1071.

RAF 34



AEROFOIL R.A.F. 34.

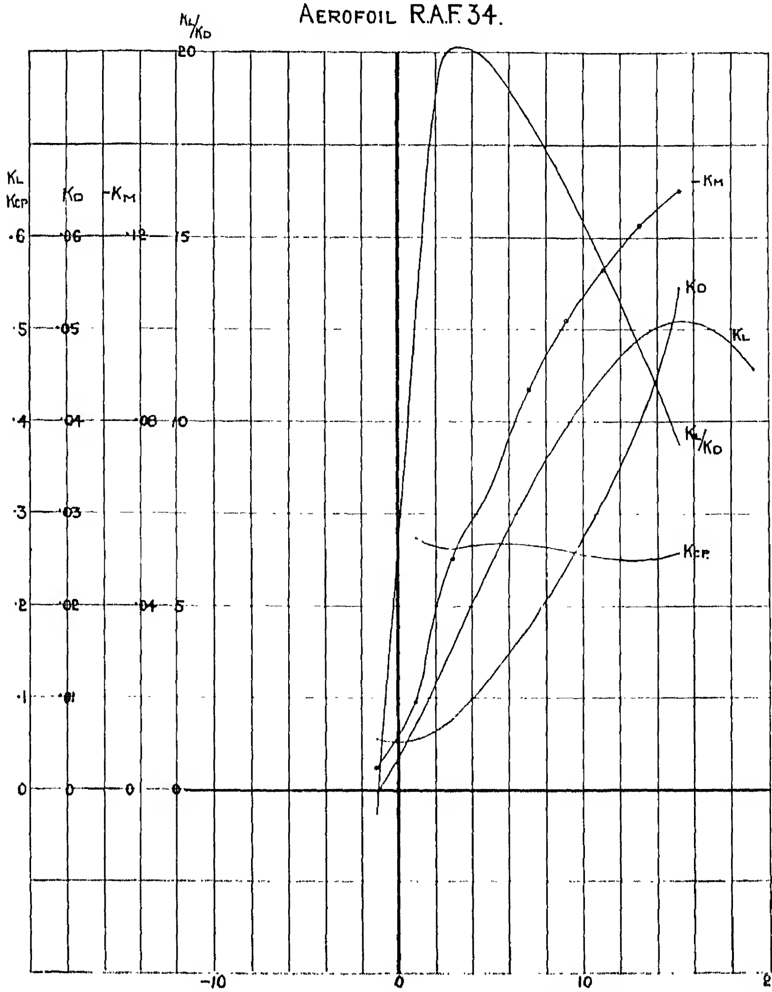


FIG. 188.

AEROFOIL CLARK Y.H.*

Size of Model	... ...	Span 30 in., Chord 5 in.
Reynolds No.	... ...	$Vc/\nu = 3{,}570{,}000$.
Wind Tunnel	... ...	N.A.C.A. Variable Density.
Year of Test	... ...	1926.

Profile.

(Co-ordinates are per cent. of chord.)

Distance from L.E.	Upper Surface.	Lower Surface.
0	3.5	3.5
1.25	5.45	1.93
2.5	6.50	1.47
5	7.90	0.93
7.5	8.85	0.63
10	9.60	0.42
15	10.685	0.15
20	11.36	0.03
30	11.70	0
40	11.40	0
50	10.515	0
60	9.15	0
65	8.30	0
70	7.41	0.06
80	5.62	0.38
90	3.84	1.02
95	2.93	1.40
100	2.05	1.85

Radius of Curvature at Leading Edge = 1.5 per cent. chord.

Coefficients.

Values relate to aspect ratio 6 and are corrected for tunnel interference.

$\alpha°$	K_L	K_D	K_{CP}	K_M	K_L/K_D
—6.1	—0.1095	0.0081	+0.130	+0.0143	—13.5
—4.5	—0.0570	0.0066	—0.051	—0.0029	—8.6
—3.0	+0.0010	0.0059	+11.730	—0.0082	+0.2
—1.5	0.0555	0.0057	0.528	—0.0292	9.7
+0.1	0.1150	0.0069	0.320	—0.0368	16.7
1.6	0.1710	0.0086	0.326	—0.0559	19.9
3.2	0.2270	0.0115	0.296	—0.0673	19.7
4.7	0.2810	0.0150	0.291	—0.0818	18.7
6.3	0.3335	0.0190	0.289	—0.0963	17.6
7.8	0.3935	0.0249	0.274	—0.1077	15.8
9.3	0.4455	0.0303	0.262	—0.1164	14.7
10.9	0.4945	0.0369	0.261	—0.1284	13.4
12.4	0.5480	0.0443	0.267	—0.1453	12.4
14.0	0.5945	0.0532	0.270	—0.1592	11.2
15.5	0.6335	0.0620	0.277	—0.1735	10.2
17.0	0.6510	0.0711	0.281	—0.1810	9.2
18.5	0.6155	0.1045	0.290	—0.1792	5.9
20.0	0.5980	0.1163	0.298	—0.1795	5.1
21.4	0.5330	0.1460	0.323	—0.1778	3.7

* N.A.C.A. note, No. 240.

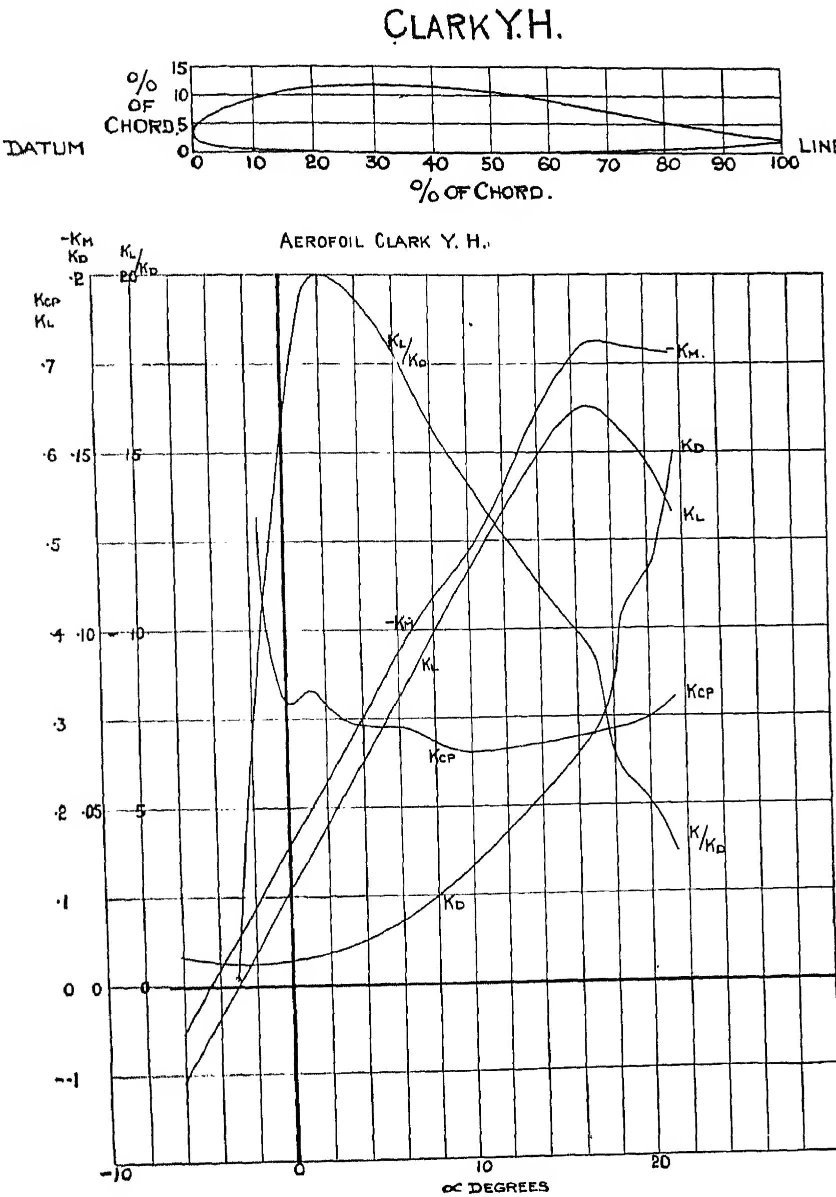

CLARK Y.H.
% OF CHORD
DATUM
LINE
15
10
5
0
0 10 20 30 40 50 60 70 80 90 100
% OF CHORD.
AEROFOIL CLARK Y. H.
-KM
KD
KL/KD
KCP
KL
·2
20
·7
·6 ·15 15
·5
·4 ·10 10
·3
·2 ·05 5
·1
0 0 0
-·1
-10
0
10
20
α DEGREES
KL/KD
-KM.
KD
KL
-KM
KL
KCP
KCP
KD
K/KD

FIG. 189.

AEROFOIL GÖTTINGEN 387.*

Size of Model	... ...	Span 30 in., Chord 5 in.
Reynolds No.	... ...	$Vc/v = 3{,}470{,}000$.
Wind Tunnel	... ...	L.M.A.L. Variable Density.
Year of Test	... ...	1926.

PROFILE.

(Co-ordinates are per cent. of chord.)

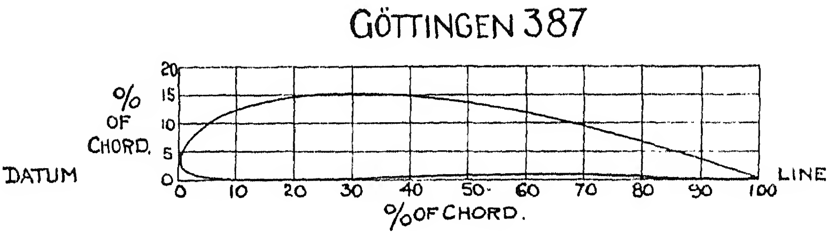
Distance from L.E.	Upper Surface.	Lower Surface.
0	3.78	3.78
1.25	6.53	1.43
2.5	7.91	0.93
5	9.89	0.40
7.5	11.32	0.15
10	12.40	0.03
15	13.84	0
20	14.71	0.05
30	15.34	0.23
40	14.85	0.38
50	13.47	0.50
60	11.54	0.57
70	9.21	0.58
80	6.58	0.49
90	3.61	0.28
95	2.02	0.16
100	0.25	0.25

COEFFICIENTS.

Values relate to aspect ratio 6 and are corrected for tunnel interference.

$\alpha°$	K_L	K_D	K_{CP}	K_M	K_L/K_D
—9.06	—0.078	0.0078	—	—0.029	—10.0
—5.98	+0.031	0.0063	—	—0.053	+4.9
—4.44	0.084	0.0070	0.807	—0.068	12.0
—2.89	0.140	0.0086	0.602	—0.084	16.3
—1.35	0.195	0.0105	0.452	—0.088	18.6
0.19	0.252	0.0142	0.401	—0.101	17.7
1.73	0.306	0.0184	0.381	—0.117	16.5
3.28	0.363	0.0234	0.351	—0.128	15.6
6.36	0.480	0.0356	0.296	—0.143	13.5
9.44	0.573	0.0502	0.304	—0.174	11.4
12.50	0.654	0.0670	0.301	—0.196	9.8
15.50	0.664	0.0924	0.332	—0.221	7.2
18.50	0.660	0.1231	0.337	—0.224	5.4
21.49	0.638	0.1501	0.350	—0.227	4.3

* N.A.C.A. Report 331.


GÖTTINGEN 387
% OF CHORD
DATUM
LINE
% OF CHORD.
20
15
10
5
0
0 10 20 30 40 50 60 70 80 90 100

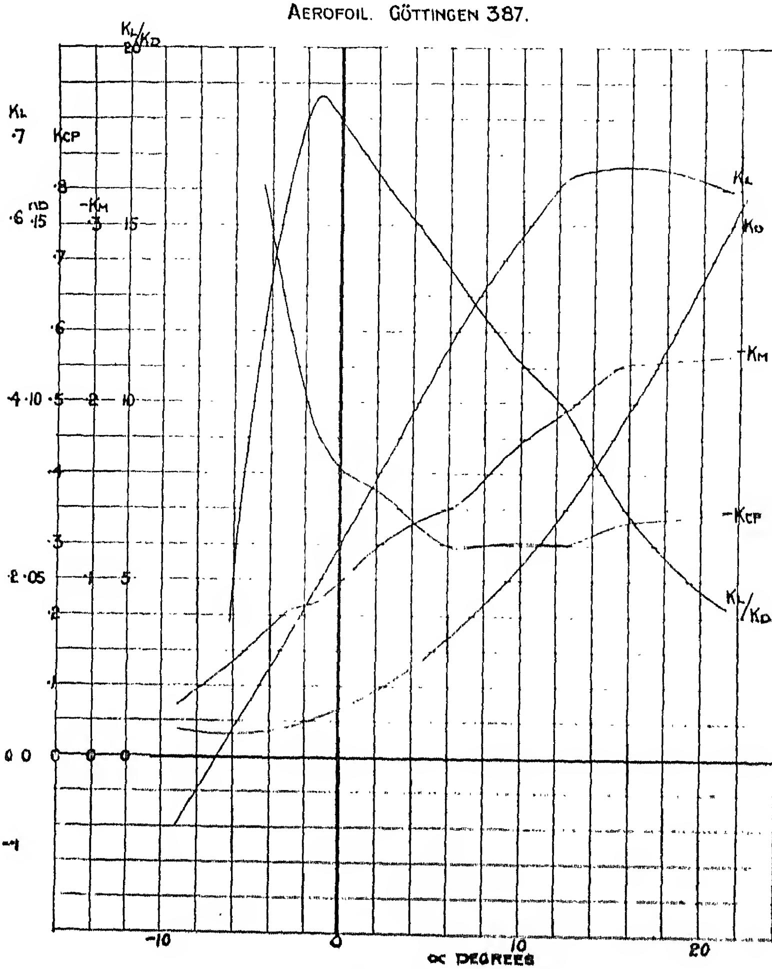

AEROFOIL. GÖTTINGEN 387.
KL/KD
KL
KCP
KD
-KM
KL
KD
+KM
-KCP
KL/KD
α DEGREES
-10
0
10
20

FIG. 190.

AEROFOIL GÖTTINGEN 426.*

Size of Model	Span 1 metre, Chord 20 cm.
Reynolds No.	$Vc/v = 410{,}000$
Wind Tunnel	Göttingen.
Year of Test	1921.

Profile.

(Co-ordinates are per cent. of chord.)

Distance from L.E.	Upper Surface.	Lower Surface.
0	3.5	3.5
1.25	5.6	1.6
2.5	6.65	1.35
5	8.2	1.05
7.5	9.4	0.75
10	10.35	0.6
15	11.85	0.35
20	12.85	0.15
30	13.6	0
40	13.15	0.15
50	11.75	0.35
60	9.9	0.65
70	7.65	0.85
80	5.25	0.9
90	2.6	0.6
95	1.25	0.35
100	0	0

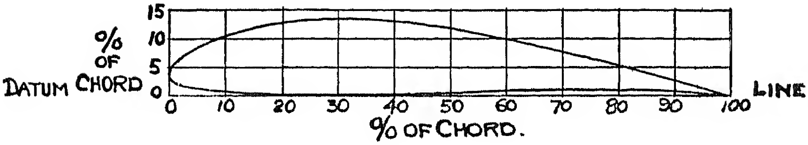
Coefficients.

Values relate to aspect ratio 6 and are corrected for tunnel interference.

α°	K_L	K_D	K_{CP}	K_M	K_L/K_D
—8.8	—0.072	0.0321	—0.18	—0.014	—2.2
—6.0	+0.036	0.0106	+1.642	—0.057	+3.4
—4.7	0.086	0.0087	0.800	—0.068	9.9
—3.3	0.136	0.0090	0.588	0.0795	15.1
—1.8	0.188	0.0106	0.506	—0.095	17.8
—0.5	0.2435	0.0124	0.444	—0.108	19.6
+0.9	0.293	0.0152	0.4125	—0.121	19.3
2.4	0.350	0.0184	0.3875	—0.135	19.0
3.7	0.400	0.0232	0.371	—0.149	17.3
5.2	0.4525	0.0278	0.352	0.1595	16.3
7.9	0.545	0.0398	0.342	—0.187	13.7
10.7	0.635	0.0567	0.333	—0.2115	11.2
13.7	0.640	0.0806	0.342	—0.220	8.0

* "Ergebnisse der Versuchsaustalt zu Göttingen," Lieferungen I and III.

GÖTTINGEN 426.



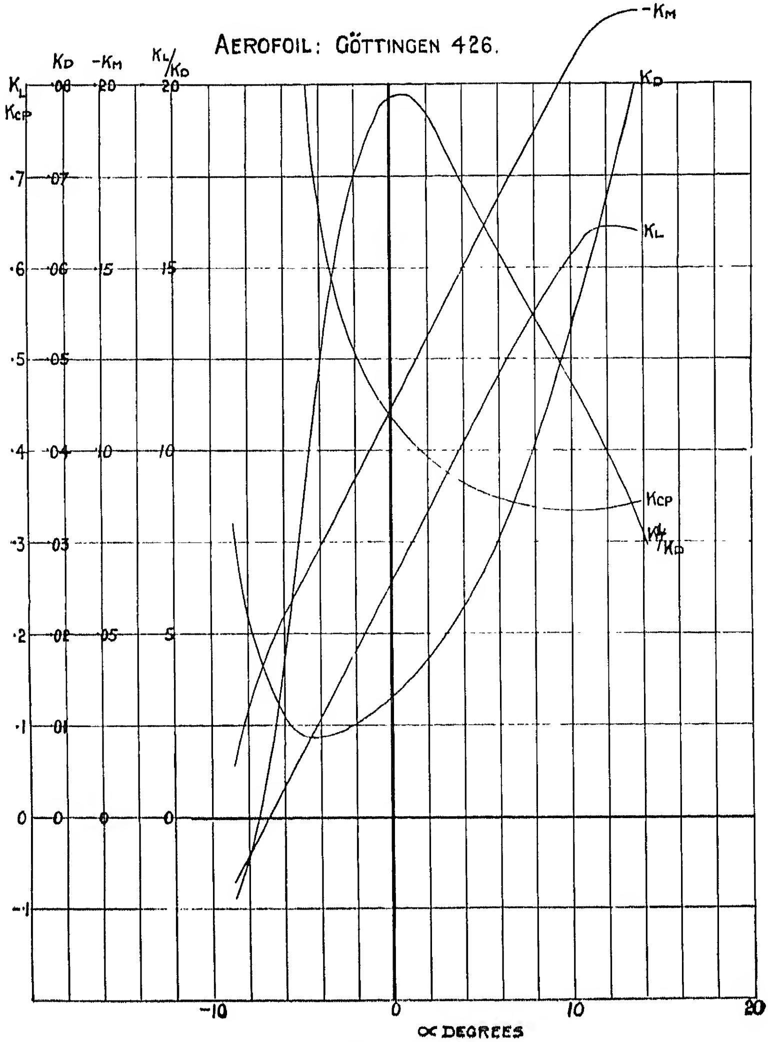


FIG. 191.

AEROFOIL GÖTTINGEN 535.*

Size of Model	...	...	Span 39.37 in., Chord 7.874 in.
Reynolds No.	...	...	$Vc/v = 4{,}840{,}000$.
Wind Tunnel	...	...	Göttingen.
Year of Test	...	...	1926.

Profile.

(Co-ordinates are per cent. of chord.)

Distance from L.E.	Upper Surface.	Lower Surface.
0	4.30	4.30
1.25	8.35	2.30
2.5	9.75	1.55
5	11.55	0.80
7.5	12.90	0.50
10	13.95	0.30
15	15.30	0.05
20	16.05	0.00
30	16.30	0.25
40	15.35	1.15
50	13.75	2.20
60	11.65	3.00
70	9.22	3.00
80	6.55	2.50
90	3.55	1.45
95	1.90	0.65
100	0.15	0.15

Coefficients.

Values relate to aspect ratio 5.

$\alpha°$	K_L	K_D	K_{CP}	L/D
−9.15	−0.018	0.0094	—	−1.916
−6.10	+0.085	0.008	0.92	+10.62
−4.60	0.138	0.0096	0.68	14.37
−3.10	0.193	0.0115	0.55	16.78
−1.75	0.25	0.0124	0.485	20.16
−0.10	0.305	0.0183	0.442	16.66
1.15	0.357	0.0226	0.415	15.80
2.75	0.413	0.0282	0.392	14.65
4.15	0.465	0.0348	0.375	13.36
5.70	0.512	0.0416	0.365	12.3
8.60	0.606	0.0573	0.35	10.6
11.55	0.694	0.0754	0.34	9.2
14.40	0.77	0.0955	0.332	8.06
17.45	0.77	0.1227	0.345	6.28

* N.A.C.A. Report 286.

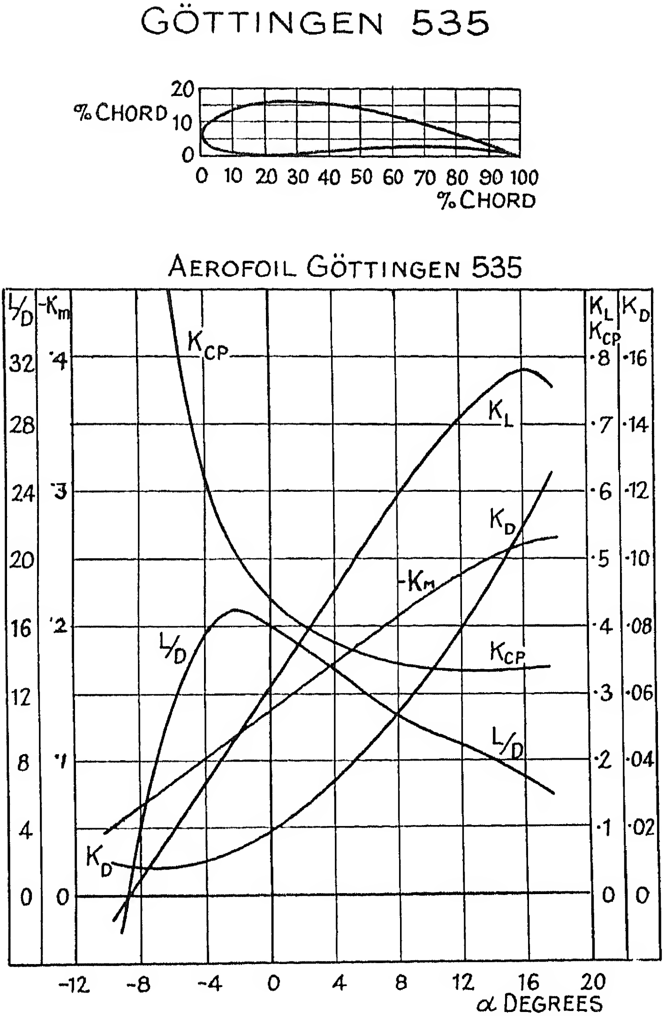

GÖTTINGEN 535
% CHORD
20
10
0
0 10 20 30 40 50 60 70 80 90 100
% CHORD
AEROFOIL GÖTTINGEN 535
L/D
-Km
KL
KCP
KD
32 ·4 ·8 ·16
28 ·7 ·14
24 ·3 ·6 ·12
20 ·5 ·10
16 ·2 ·4 ·08
12 ·3 ·06
8 ·1 ·2 ·04
4 ·1 ·02
0 0 0 0
-12 -8 -4 0 4 8 12 16 20
α DEGREES

Fig. 192.

AEROFOIL GÖTTINGEN 549.*

Size of Model	... ...	Span 39.37 in., Chord 7.874 in.
Reynolds No.	... ...	$Vc/v = 4{,}840{,}000$.
Wind Tunnel	... ...	Göttingen.
Year of Test	... ...	1926.

PROFILE.

(Co-ordinates are per cent. of chord.)

Distance from L.E.	Upper Surface.	Lower Surface.
0	3.45	3.45
1.25	5.70	1.95
2.5	6.80	1.60
5	8.45	1.10
7.5	9.65	0.75
10	10.70	0.55
15	12.25	0.25
20	13.20	0.05
30	13.85	0.00
40	13.40	0.10
50	12.05	0.30
60	10.05	0.55
70	7.90	0.65
80	5.35	0.55
90	2.70	0.30
95	1.40	0.15
100	0.00	0.00

COEFFICIENTS.

Values relate to aspect ratio 5.

$a°$	K_L	K_D	K_{CP}	L/D
—8.8	—0.085	0.034	—	—2.5
—6	+0.01	0.0077	—	+1.298
—3	0.115	0.0074	0.624	15.74
—0.1	0.218	0.011	0.45	19.82
2.8	0.321	0.0178	0.38	18.04
5.8	0.424	0.0283	0.35	15
8.6	0.524	0.042	0.34	12.46
11.7	0.616	0.0582	0.325	10.6
14.5	0.665	0.078	0.322	8.52
17.5	0.626	0.101	0.325	6.2

* N.A.C.A. Report 286.

GÖTTINGEN 549

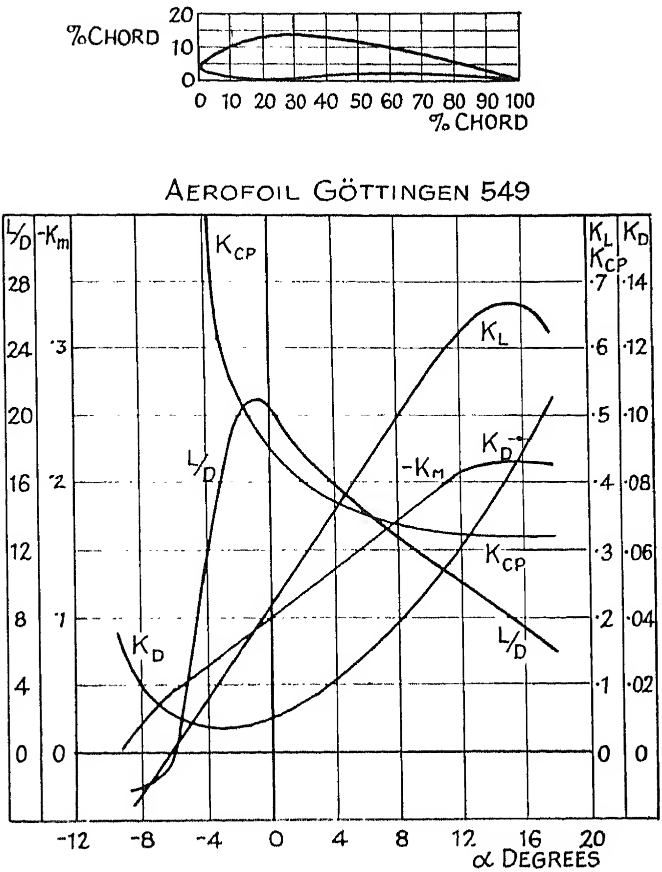


FIG. 193.

APPENDIX III

B.G.A. Regulations Governing Mechanical Launching

APPROVED METHODS

The following methods are at present approved for general use:

1. The launch is made with the aid of one motor-car attached to the glider with about 60 ft. of double 5/8 in. shock cord and a length of rope of at least 100 ft. For launching the glider faces directly into wind with the car in front, the tail being held back in the usual manner. A small flag, or other suitable mark, is placed in front of the car at a distance equal to the length of elastic. The launch is made by driving the car forward until the shock cord is stretched to double length, as determined by the fixed mark, when the release is made. As soon as the elastic falls clear of the glider the car is driven to the left to avoid collision.

2. This method is similar to (1), but employs a pulley affixed to the ground at a distance of at least 200 ft. in front of the glider, at which point the rope is turned through an angle of 90°, or thereabouts, so that the motor-car is driven in a direction at right angles to that of the glider. Regulation (3) is of the utmost importance with this method of launching.

REGULATIONS

Note.—Mechanical launching has a greater element of danger than the orthodox team method and if used extreme care should be exercised.

These regulations refer only to launching done with the aid of a motor-car in place of the usual launching crew. (Auto-towing is covered by separate regulations.)

1. Only methods of mechanical launching as approved by the B.G.A. shall be used. Clubs or individuals wishing to

make use of other methods must first submit full descriptions of their scheme for approval by the B.G.A.

2. Mechanical launching shall only be used when a capable instructor superintends its use.

3. For any method of mechanical launching, a quick release, operable by the pilot, must be incorporated with the launching hook. The release lever shall be as close to the pilot's hand as can be arranged. The launching hook shall be of the open " drop off " type.

4. The speed and direction of the wind must be carefully measured or estimated and allowed for in the speed of the launch.

5. The joint between the cable and shock cord must be well made and periodically inspected.

RECOMMENDATIONS

1. Private groups are recommended not to employ mechanical launching unless in possession of at least the " B " certificate.

2. A pilot flying any new type of machine should receive gentle launches for the first few flights and these should be made by the shock cord method.

3. It is recommended that the pilot should not give the command " release " at the launch, but that this should be done by someone near the machine on receiving a signal from someone in the car, or standing near the flag or mark.

4. In any method employing the use of a pulley, care should be taken to make sure that it is well fixed to the ground by two or more long stakes, driven well in and roped together, and the pulley should be kept well greased to prevent overheating and possible seizure. A pulley with large flanges is recommended and it should not be possible for the rope to ride over or jam in any way.

5. If the shock cord is inserted between the car and the cable there is little likelihood of either the pilot or the machine getting damaged in the event of a breakage of the shock cord.

APPENDIX IV

B.G.A. Regulations Governing Auto-Towing

OPERATION

Ab-initios.—As a first step the beginner should be towed at a little under flying speed, so that, although the glider responds to the movements of the rudder and elevator, the glider cannot leave the ground. The length of cable used at this stage should be 150 ft. By this means the pupil learns to keep on a straight course and to maintain the fore and aft trim. If he veers to one side the car is accelerated and the nose of the glider is thus jerked straight into line with the car. It is important that the cable should not be released when the pupil yaws, as this would probably cause the glider to cartwheel on one wing-tip. Ab-initio training should not be carried out on a gusty day, as the machine will be liable to leave the ground under the influence of gusts.

Second Stage.—The speed of the car is slightly increased so that the pupil is able to fly behind the car at a height of a few feet above the ground. Any inclination on the part of the pupil to fly higher than this should be immediately repressed by a gradual deceleration of the car, which will cause the machine to land, when the instructor should correct his fault before commencing another flight. Height can be gained very rapidly during auto-towing, and the pupil is liable to be disconcerted at finding himself very high. Further, while the machine is much more under the control of the car when flying between 6 and 8 ft. high, it is also easier for the pupil to recognise changes of altitude when so near the ground. He therefore learns to fly on a steady flight path. By gradual stages the altitude of the glider is increased to 20 and then to 50 ft., still being assisted in landing by regulating the speed of the car. The length of the cable should be increased in proportionate stages to 300 ft. During the first and second

stages, the cable release must be locked so as to prevent inadvertent operation by the pupil.

Third Stage.—When the pupil has proved that he is master of the glider on these "attached flights," he is again towed a few feet above the ground and is allowed to cast off the towing cable and land himself. After this he is towed a little higher, and must make gentle turns to left and right through an angle of roughly 20° and land into wind in the direction of the take-off. After attaining proficiency in these turns and landings he is allowed, on a calm day, to make a semi-circular turn from a height of 50 to 80 ft. before landing.

Fourth Stage.—The pupil should now be taken to a hill site for practice in soaring flight.

OBSERVATIONS

The critical time in auto-towing is between attaining flying speed and reaching a height of 20 or 30 ft., particularly if the wind varies. Extra care is necessary during this period.

A great deal of responsibility rests on the instructor, because he must be able to anticipate and quickly correct any mistakes made by the pupil.

Care should be taken in choosing the driver of the car, who should be able to re-act quickly to the orders of the instructor. No gear change may be made after the glider leaves the ground. It is found that a slight decrease in the speed of the car is necessary when the glider leaves the ground, due to the increase in air speed caused by the climb.

The instructor shall inform the driver of the car, before starting the flight, the air speed to be attained and to be maintained.

All training must be carried out directly into wind.

To allow for varying lengths of cable necessary, a winch should be securely fastened to the car as near to the central position of the chassis as possible. This winch should be fitted with an efficient brake.

The cable must be kept free from kinks or weak places, because if it breaks, while the glider is just taking off, the machine is very liable to stall.

If at any time during the flight the pilot feels the tow relax, he should level out, operate the release and immediately

put the machine into its gliding angle. The pilot at all times must assure himself that the cable has actually been released, as otherwise a bad accident may result.

During a flight, in the third stage, if the instructor observes that the pilot has failed to release the cable, or the cable remains attached, he should immediately have the cable released at the car end, and failing this he should instruct the driver of the car to follow the glider so as to remain as close as possible.

REGULATIONS

1. All gliders used for auto-towing must have a special Certificate of Airworthiness for that purpose issued by The British Gliding Association. For training purposes a single track undercarriage (i.e. one with a single wheel and/or skid) is inadvisable.

2. Any existing glider, holding a normal C. of A., which is to be adapted for auto-towing must be re-approved for the special C. of A. For this an appropriate fee will be charged.

3. The towing hook shall be fitted with a "fool-proof" release with the operating device close to the pilot's hand and shall be of a type approved by The British Gliding Association.

4. Means for locking the release should be provided. (It is essential that beginners should be entirely under the control of the instructor.)

5. The towing cable shall be of not less than 10 cwt. breaking strength and of extra flexible construction. It must be examined before each flight. A shock absorber consisting of a double link about 15 in. in length of $\frac{5}{8}''$ braided elastic cord with 10 cwt. check cable to allow 50 per cent. extension, should be fitted. Good quality $\frac{3}{8}''$ diameter sash cord may be used in lieu of steel cable if desired.

6. An air-speed indicator must be mounted on the car well within the vision of the driver and connected to a pitot head mounted on a strut, at least 5 ft. above any part of the car.

7. An instructor with experience of auto-towing shall always be in the car with the driver, seated in such a position that the glider and pupil are in full view throughout the flight.

8. A separate master throttle control shall be fitted near the winch brake, in order that the instructor can regulate the speed of the car in an emergency.

9. The towing car shall be of sufficient power and reliability to make a quick "get-away" and avoid stalling the glider close to the ground. A minimum of 20 h.p. is recommended.

10. On wet grass, or on ground where wheel-slip is likely to occur, chains should be fitted to both driving wheels.

11. The glider shall be fitted with adequate harness for the pilot (and passenger). Harness to be of a type approved by the B.G.A.

12. If primary type gliders are used for auto-towing they shall not be taken to a greater height than 10 ft. above the ground. Any infringement of this regulation will entail suspension of the Certificate of Airworthiness.

13. The point of cable attachment shall be within the limits as specified below:

(*a*) For elementary training purposes: Within the angle formed by lines drawn through the C.G. position (loaded), forwards and downwards, at 10° and 40° to the horizontal, and

(*b*) For advanced work: Within the angle formed by lines drawn through the C.G. position (loaded), forwards and downwards, at 10° and 80° to the horizontal. (See Fig. 194.)

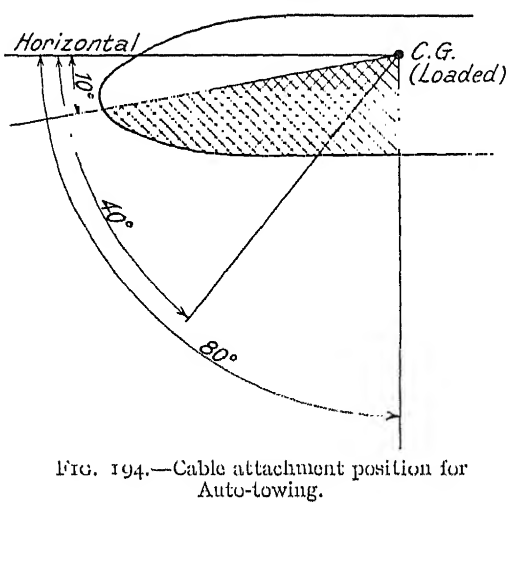


FIG. 194.—Cable attachment position for Auto-towing.

APPENDIX V

B.G.A. Regulations Governing Aeroplane-Towing
(*Provisional*)

1. No sailplane, or glider, shall be used for aero-towing unless in possession of a current B.G.A. Certificate of Airworthiness duly endorsed for aero-towing. Proof that the necessary strength requirements have been complied with will have to be shown.

2. Gliders shall only be towed by aeroplanes properly equipped for aero-towing, approved by the Air Ministry, and with the Certificate of Airworthiness endorsed to that effect.

3. The towing cable shall include a " weak-link " to fail at a load equal to the loaded weight of the glider. The link to be fitted at the glider end of the cable.

4. The strength requirements, extra to those for normal category gliders, are :

(*a*) The fuselage shall be capable of withstanding a load at the cable attachment position of 200 lbs. horizontally, changing to 250 lbs. vertically, with a factor of 2.

(*b*) Suitable drag-bracing shall be present.

A towing speed of 45 m.p.h. has been assumed.

5. No elementary training type of glider will be approved for aero-towing.

6. Only pilots in possession of a " C " Soaring Certificate will be allowed to pilot gliders being towed by aeroplane.

7. A minimum length of 300 ft. is suggested for the cable.

8. Towing cables must be dropped by the towing aeroplane over an aerodrome so as to fall clear of all buildings and persons.

9. All sailplanes must have a release definitely operable by the pilot.

AIR MINISTRY NOTICE

Use of Aircraft for Towing Gliders

1. Only aircraft specifically approved for the purpose are to be used for towing gliders.

2. When such approval is required application is to be made in the first instance to the Secretary, Air Ministry (C.A.2), Adastral House, Kingsway, London, W.C. 2, and at the same time full details of the proposed scheme are to be forwarded to the Chief Superintendent, Royal Aircraft Establishment, Farnborough, marked for the attention of the Airworthiness Department.

3. Before approval is given it will be ascertained that the structure has an adequate margin of strength under loads from the towing cable, and that the control of the aircraft will not be endangered when the pull on the aircraft from the towing cable acts in any reasonably probable direction.

4. A weak link, which shall break at some predetermined load, is to be included in the towing cable near its point of attachment to the towing aircraft, the load referred to being fixed after consideration of the details of the towing arrangement proposed.

5. Quick releases, under the control of the pilots of the aircraft and glider respectively, are to be fitted at both ends of the towing cable.

6. Suitable provision is to be made to guard against the tow rope fouling any part of the aircraft, both when under load and when released or slackened by the glider overtaking the aircraft.

Air Ministry,
London, W.C. 2.
10th September, 1931.

APPENDIX VI

B.G.A. Inspector's Report on Construction of Glider for Certificate of Airworthiness

Type of Glider..............................

Constructors ....

Owner ....

Name of Inspector.................. *Date*..........

A.—Timber.

1. State kind of timber, and grade, used in construction.
2. Does this comply with the drawings and specifications ?
3. Is the timber and plywood of good quality for all stressed components ?
4. If any defects are present, such as knots or crooked grain, state nature of defects and positions.
5. Give particulars of all joints and splices in the main spars and longerons. State angle of splice.
6. Have all plywood joints on the leading edge and fuselage been well feathered ?
7. Have all glued joints been properly made and under pressure ?
8. Has a good quality glue been used ?
9. Are all holes properly drilled ?
10. If any king-posts are employed, are they well made with grain parallel to the length, plywood covered, held firmly with fillets, and copper lined at the cable connection point ?
11. Has all woodwork been treated against weather effects ?

B.—Fittings and Metal Parts.

1. Has only metal to aircraft specification been used for all stressed parts ?

2. Are tubes, wires, cables and bolts to aircraft specification?
3. Are any hinges held by wood screws?
4. Have all bolts been properly secured with nuts and split pins or spring washers?
5. Have large washers been fitted to all bolts and nuts resting on wood?
6. Are all bolts used in the control system burred over? If not, how are they locked?
7. Have all wire eyelets and splicings been properly made, and heart thimbles inserted in cable splicings?
8. Have all bolts been inserted with their heads upwards or forwards?
9. Have all metal parts been suitably treated against corrosion before assembling?
10. Are all welded joints sound?
11. Are all joints and pulleys well greased or lubricated?
12. Do all the pulleys run freely? Are they fitted with guards, and set in the direction of pull in the cable?
13. Can all pulleys be easily inspected?
14. Do all control cables run clear of structural members?
15. Are the controls free from backlash?
16. Are any of the control levers subjected to undue initial tension?
17. Are any bracing wires unduly tight, causing undue initial tension?

C.—General.

1. Are all controls correctly connected?
2. Do all dimensions agree with the drawings? Check spars, gauge of fittings, bolts, struts, and strength of wires and cables.
3. What is total weight of machine (less pilot)?
4. What is the position of the centre of gravity of the machine (with pilot), as determined by weighing?
5. Is the control column central with all control surfaces in their neutral position?
6. Are the following correct:
   - Wing angle of incidence?
   - Fuselage at right angles to wing, horizontally and vertically?
   - Tail unit setting to main plane?

7. Is fabric satisfactory, properly attached and doped, waterproof, and provided with moisture outlets ?
8. Is the fuselage provided with water outlets ?
9. Have precautions been taken (by upholstering the cockpit) to protect the pilot in the event of a crash ?
10. Is a satisfactory harness fitted ? Does it attach to a main member ? Is it sprung ?
11. Is the launching hook strong and well shaped ?
12. Is there any possibility of the launching rope catching on the skid front or any other member ?
13. Has provision been made for holding back the machine during the launch, and are the loads so imposed properly transmitted to the longitudinal members ?
14. Test all control surfaces for rigidity and torsion.
15. Oscillate the wing-tip by imparting gentle pushes, and time the beats. State number of complete beats per minute.
16. Give a general report on the construction of the complete machine.

APPENDIX VII

TABLE 7

STRENGTH AND WEIGHT OF BIRCH PLYWOOD[1]

ALLOWABLE STRESSES

Tension.	Parallel to outer grain	13,000 lbs./sq. in.
	Across outer grain	6,500 ,, ,,
Shear.	Across grain of outer ply	2,500 ,, ,,
	Parallel to grain of outer ply	2,200 ,, ,,
	At 45° to grain	2,000 ,, ,,
	Torsional shear of plywood tube with outer plies parallel to the tube axis	1,400 ,, ,,

R.R.G. FIGURES FOR TORSIONAL SHEAR OF PLYWOOD

Outer plies parallel to axis	1,150 lbs./sq. in.
,, ,, perpendicular to axis	1,400 ,, ,,
,, ,, at 45° to axis	2,500 ,, ,,

Note 1.—The plywood is glued under pressure, which forces the glue into the grain and considerably strengthens the plies.

,, 2.—All the above figures are for dry plywood. In a wet or damp state the strength is greatly reduced. All exterior plywood should be protected by varnish.

Weights (Approximate).

Thickness mm.	0.8	1.0	1.5	2.0	2.5	3.0
,, in.	1/32	—	1/16	—	—	1/8
Weight lb./sq. ft.	0.145	0.17	0.25	0.34	0.4	0.48

[1] From tests carried out by the Author.

Table 8

Extra Flexible Steel Wire Rope for Auto- and Aero-Towing

Item.	Minimum Breaking Strength. Cwts.	Maximum Diameter. Inches.	Construction.	Weight of 100 ft. Lbs.
4	5	.08	7×7	1.11
5	10	.12	7×14	2.22
6	15	.15	7×19	3.75
3	20	.16	,,	4.2
51	25	.18	,,	5.0

Table 9

Sizes and Strengths of Streamline and Swaged Wires

Size.	Area of Oval.		Area of Swaged Portion. Inches.	Ultimate Strength. Lbs.
	Minimum.	Maximum.		
4 B.A. . .	.0071	.0085	.0085	1,050
2 B.A. . .	.0126	.0142	.0129	1,900
$\frac{7}{32}''$ . .	.0174	.0191	.0174	2,600
$\frac{1}{4}''$ . .	.0233	.0250	.0230	3,450
$\frac{9}{32}''$ . .	.0314	.0338	.0337	4,650
$\frac{5}{16}''$ . .	.0372	.0400	.0391	5,700
$\frac{11}{32}''$ . .	.0473	.0508	.0495	7,150
$\frac{3}{8}''$ . .	.0561	.0603	.0590	8,500
$\frac{13}{32}''$ . .	.0683	.0734	.0721	10,250
$\frac{7}{16}''$ . .	.0778	.0836	.0835	11,800
$\frac{15}{32}''$ . .	.0921	.0990	.099	13,800
$\frac{1}{2}''$ . .	.103	.1107	0.1116	15,500
$\frac{9}{16}''$ . .	0.139	—	0.140	20,200
$\frac{5}{8}''$ . .	0.168	—	0.1713	24,700

TABLE 10

HIGH TENSILE STEEL WIRES (SPEC. 2. W.1)

Gauge.	Diameter in Inches.	Full Strength. lb.	65% Strength. lb.
8	.160	3,600	2,340
9	.144	2,920	1,900
10	.128	2,450	1,590
11	.116	2,130	1,385
12	.104	1,710	1,110
13	.092	1,340	870
14	.080	1,070	696
15	.072	866	563
16	.064	720	468
17	.056	552	359
18	.048	405	263
19	.040	282	183

Column 4 shows 65% strength of the wire to allow for the usual type of end fixings.

TABLE II

WEIGHT AND STRENGTH OF MATERIALS

Material.	Specification.	Weight lbs./cu. in.	Modulus E. lbs./sq. in.	Tensile lbs./sq. in.	Compressive lbs./sq. in.	Bearing lbs./sq. in.	Shear lbs./sq. in.	Remarks.
Spruce	(Grade A)	.0156	1.5×10^6	9,000	4,500[1] (end grain)	3,100	Longitudinal, 800 Normal to grain, 1,200	...
Plywood	B.E.S.A., 3V3	.024	1.3×10^6	12,800 with grain 6,400 cross grain	...	...	With[2] grain, 2,200 Cross grain, 2,500 Diagonally, 2,000	...
Ash	...	.0231	1.7×10^6	9,000	5,500	3,100	Longitudinal, 800 Normal to grain, 1,200	...
Mild Steel Sheet.	B.E.S.A., 2S.3	.28	...	62,700		94,000	48,300	Suitable for welding.
Low Tensile Steel Sheet	D.T.D.39	.28	...	62,700–78,400		...	...	Non-corroding.
Steel Bar	B.S.S., 3S.1	.28	...	78,400–101,000	As Tensile Figures	110,000	57,000	Bolts, etc.
Steel Bar	D.T.D., 53	.28	...	78,400		...	...	Non-corroding.
Carbon Steel Tube	B.E.S.A., T.1	.28	...	78,400		100,000	50,000	Oval tubes.
Annealed Carbon [illegible]	B.E.S.A., [illegible]	.28	...	62,700		80,000	43,000	...

Carbon Steel Tube	B.E.S.A., T.5	.28	...	110,000		150,000	60,000	Struts.
Mild Steel Tube	B.E.S.A., T.26	.28	...	44,800		...	...	Sockets, etc.
Mild Steel Tube	B.E.S.A., T.6	.28	...	67,200		...	...	Suitable for welding.
Carbon Steel Tube	D.T.D., 89A.	.28	...	101,000		...	...	Suitable for welding.
Low Tensile Steel Tube	D.T.D., 97	.28	...	62,700		...	...	Non-corroding.
35-ton Steel Tube	D.T.D., 102	.28	...	78,400	As Tensile	...	...	Non-corroding.
Aluminium Sheet	B.E.S.A., 2L.17	.1	...	11,200–14,600	Figures	...	...	Soft.
Aluminium Bar	B.E.S.A., 2L.22	.1	...	27,100		...	...	...
Aluminium Tubes	3T.9	.1	...	15,700–22,400		...	...	...
Duralumin Sheet	B.E.S.A., 2L.3	.1	...	56,000		75,000 rivet joints, 48,000 bolt holes	26,000	...
Duralumin Bar	B.E.S.A., 3L.1	.1	...	56,000		75,000	26,000	...
Duralumin Tube	B.E.S.A., 3 T.4	.1	...	58,200	64,000	70,000	35,000	...

Note 1.—The allowable stress of spruce in bending is 5,000 lbs./sq. in. Note 2.—The shear stress of plywood in torsion is 1,100 grain parallel to axis, 1,400 perpendicular and 2,500 diagonally. All figures in lbs./sq. in. (See Table 7.)

Table 12

Conversion of English to Metric Weights, Measures, and Velocities

English.		*Metric.*
1 lb.	=	.4536 kilogrammes.
1 inch	=	25.3995 millimetres.
1 inch	=	.0253995 metres.
1 foot	=	.3048 metres.
1 yard	=	.91438 metres.
1 mile	=	1.609 kilometres.
1 square inch	=	6.4514 square centimetres.
1 square foot	=	.0929 square metres.
1 square yard	=	.8361 square metres.
1 lb. per sq. inch	=	.0007 kilogrammes per square mm.
1 cubic inch	=	16.3862 cubic centimetres.
1 cubic foot	=	.0283 cubic metres.
1 lb. per foot	=	1.488 kilogrammes per metre.
1 lb. per sq. foot	=	4.883 kilogrammes per sq. metre.
1 ft. per sec.	=	.3048 metres per sec.
1 mile per hour	=	1.6093 kilometres per hour.

Metric.		*English.*
1 kilogramme	=	2.20462 lbs.
1 millimetre	=	.03937 inches.
1 centimetre	=	.3937 inches.
1 metre	=	39.3708 inches.
1 metre	=	3.281 feet.
1 metre	=	1.094 yards.
1 kilometre	=	1903.633 yards.
1 kilometre	=	.6214 miles.
1 sq. centimetre	=	.155 sq. inches.
1 sq. metre	=	10.7643 sq. feet.
1 kg. per metre	=	.672 lbs. per foot.
1 kg. per sq. mm.	=	1422.28 lbs. per sq. inch.
1 kg. per sq. m.	=	.2048 lbs. per sq. foot.
1 metre per sec.	=	3.281 ft. per sec.
1 kilometre per hr.	=	.621 mile per hour.

(*Note.*—1 foot per sec. = .682 mile per hour.)

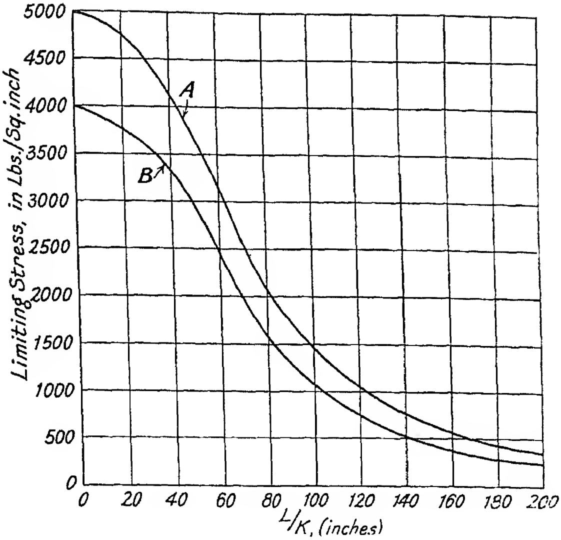


FIG. 195.—Spruce Struts, Limiting Stress (Robertson). Grades A and B Spruce.

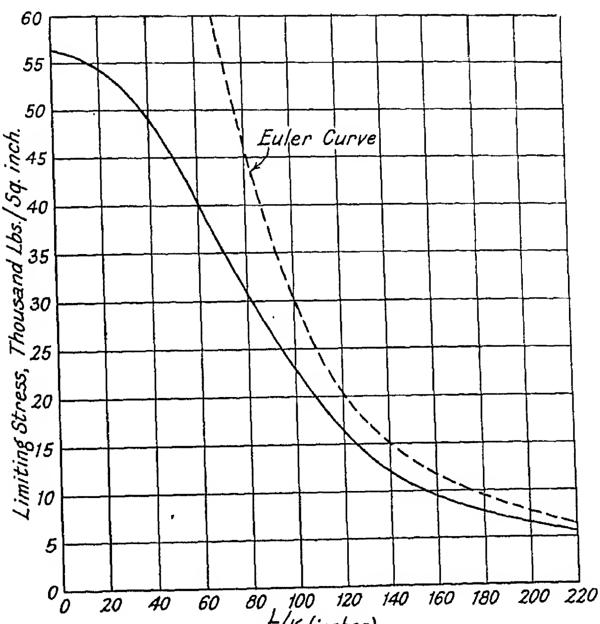


FIG. 196.—Tubular Steel Struts, for 28-Ton Steel.

INDEX

ABBOTT, E. D., Ltd., 123
Aerofoil, R.A.F. 30, 232
R.A.F. 34, 234
Clark YH, 236
Göttingen 387, 238
Göttingen 426, 240
Göttengen 535, 242
Göttengen 549, 244
Characteristics, 16–19
Aero-towing, 207–216
regulations, 252
Ailerons, 5, 11, 85
area, 31, 32
construction of, 133
differential, 32
Air brakes, 102
Airspeed, Ltd., Messrs., 121
Air-speed indicators, 218
Airworthiness certificate, inspector's report, 254
regulations, 4
" Albatross," the, 117
Altimeter, 220
Alula, 108
Aluminium, 165, 261
Anemometer, pressure plate, 219
rotating cup, 219
venturi, 218
Angle of attack, aspect ratio effect, 227
Area, aileron, 31
elevator, 31, 32
rudder, 31, 32
tail, 31
Ash, 164, 260
Aspect ratio, 20, 22, 35, 229
effect of on angle of attack, 227
" Austria," the, 117
Auto-towing, 216
regulations, 248–251

B.A.C. 7, the, 119
Barograph, 221
Batten, J. D., 100
Baynes, L. E., 123
Bays, drag, 49
Bending moment diagrams, 42–46
moment due to landing loads, 46
resistance to, 56
Bending and torsion, combined, 57
Bewsher, J., 119
B.G.A. Inspector's report, 254–256
Regulations for airworthiness, 4
Regulations governing aero-towing, 252
Regulations governing auto-towing, 248–251
Regulations governing mechanical launching, 246
Biplane, 13–14
Bird form (for sailplane wings), 106–110
Birds, soaring, 110
Brads, 166
Brakes, air, 102
Brustmann, Dr., 101
Bulkheads, 74, 78

CABLE, towing, 208
Cables, 88, 167
Casein (see cement)
Cement, 165
Centre of gravity, 32–34
pressure, 33–34
pressure movement, 17
Cloud flying, 198
Cloudcraft Glider Co., 121
Coefficient of lift, 16
Compass, 220
Conditions of loading, explanation of, 5
Contour soaring, 192
Control cable connection, 157
column, 89, 158
rudder, 160
surfaces, size of, 30–32
system, 157–162
system loads, 12, 87
wheel, 159–160
Convection soaring, 192

" DARMSTADT II," the, 114
Diagrams, bending moment, 44–46
load, 46–47
rib load, 59
Dibovsky, Capt., 99
Dihedral, 37
Dive, limiting velocity, 6–10, 50, 51
pull-out of, 10–11
Dope, 135, 166
Drag, bays, 49
bracing (tail-plane), 85
coefficient, fuselage and tail, 8, 34–36
induced, 17, 35, 36, 225
loads, 49
profile, 17, 18, 36, 225, 230
Dunstable, 173
Duralumin, 165, 261
Dynamic flight, 191, 201
Dyott, Squadron-Leader G. M., 196

ELASTIC, launching, 177, 180
Elevator, area, 31
attachment fitting, 154
loads, 8–10
Elevators, 142–144
Empennage, 142–144
End effect, 40, 48
End load, 47, 48, 66

FABRIC, 135, 166
tension, 59
Factors, loading, 3–5
loading, American, 8, 11
" Fafnir," the, 116
Fin, 144
Fittings, 89
construction of, 145–157
elevator attachment, 154
leading-edge/fuselage, 147
skid attachment and launching hook, 153
spar connection, 90, 148–150
spar/fuselage connection, 92, 146
strut end, 151
strut/fuselage, 152
strut/spar, 152
tail unit, 153–155
Flapping wing machines, 98–102
Fuselage, 4, 5, 10
and tail, drag coefficient, 8
construction of, 136–140
centre of gravity of, 33
cross-section of, 29
drag, 34–36
Fuselage, girder, 138
main frame, 76, 137
monocoque, 136
shape, 26–30
types, 71
weight, 15

GENERAL arrangement of sailplane, 36–37
Georgii, Dr. W., 199, 202
Gliding angle, best, 39
Glue, 165
Groenhoff, 199

HILL soaring, 192
Hinges, 154, 155
Hook, launching, 153
Hurtigg, 203

INCIDENCE, angle of, 34–36
Induced drag, 17, 35, 36
component, 225
theory of, 225
Inspector's report, B.G.A., 254–256
Instruments, 218–221
provision for, 30
Inverted flight, 68

JOINTS, spliced, in timber, 167

" KAKADU," the, 114
King-posts, 88
construction of, 155–156
Kronfeld, R., 113, 117, 199
Kupper, Dr., 97, 117

LACHMANN, Dr., 14, 15
Lanchester, Dr. F. W., 195, 202, 204
Landing, 176, 188
gear, 4, 10, 11
load, 46, 68
speed, 28
Launching, 176, 178–181
elastic, 167
hook, 153
mechanical, 182
Leading-edge, construction of, 131
Lift coefficient, 16
drag ratio, 16
struts, 60
Lippisch, Herr A., 15, 22, 98, 202
Load, diagrams, rib, 59
tail, 6–10
on main plane, curve for, 40–41

Loading, factors of, 3, 5, 8
 nett, 41
Loads, control system, 12
 distribution of, 50
 drag, 49
London Gliding Club, 173
Longerons, construction of, 138
 design of, 73
" Luftikus," the, 115

MAIN plane calculations, 60
 construction, 127
 loading during take-off, 181
 ribs, 57
 spars, strength of, 56
Main planes, factors of loading, 4, 5
 load curve, 40–41
 plan form, 19–22
Materials of construction, 163–167
 weight and strength table, 260–261
Mechanical launching, 182
 regulations, 246–247
Moment curve, 8
Monocoque fuselage, 71, 77–79
Multi-aerofoil, 110
Multi-slots, 104–106

NEHRING, 109
Nose dive, terminal velocity, 6–10, 50, 51

ORNITHOPTERS, 98–102
Oscillation of wings, 24

PEDALS, rudder, 161
Performance, 37–39
" Phantom," the, 121
Pins, connecting, 147
 attachment, 150
Plywood, 164, 260
 birch, strength and weight tables, 257
Polar curve, 8, 34–35
" Power " factor, 17
Prandtl, Dr., 102
" Professor," the, 113
Profile drag, 17, 18, 36, 225, 230

RELEASES, automatic, 179
R.F.D. Co., 117, 119
R.F.D. sailplane, the, 119
Ribs, main plane, construction of, 129
 main plane, load curve, 58
 main plane, load diagrams, 59
Ribs, main plane, spacing, 57
 tail plane, 85
R.R.G. strength regulations, 5
Rudder, 10, 85
 area, 31
 construction of, 144
 control, 160
 factor of loading, 4, 5,
" Rhönadler," the, 115

SAILING flight, 191
" Schloss Mainberg," the, 114
" Scud," the, 123
Secondary failure, 48–49, 66
Sempill, the Master of, " Foreword "
Sesquiplane, 14
Shear forces, 47, 48
 load, horizontal, 48
 resistance to, 57
Sinking speed, 22, 38
Site, dimensions, 173
 for distance flights, 176
 soaring, 171–177
Skid attachment fittings, 153
 landing, 79, 137, 140
 tail, 37, 80, 141
Slots, multi-, 104–106
Slotted wings, 103
Soaring, 186
 convection, 193
 hill or contour, 192
 methods of, 191
 storm, 201
Spar arrangement, 52, 53
 secondary, 52, 53
 sections, 53–54
 [illegible] sections, 54
 [illegible]
 load distribution, 50
 main plane, strength of, 56
 tail plane and elevator, 83
 the main, 128
 two-spar wings, 51, 52
Speed effect (towed flight), 215
 landing, 28, 37
 minimum, 28
 of flight, 187
 optimum, 39
 sinking, 22, 38, 39
 stalling, 37
Spliced joints, 167
Spruce, 164, 260
 struts, limiting stress, 263
Stalling speed, 37
Steel, 165
 sheet, bar and tubes, 260

Steel, struts, limiting stress, 263
wire rope for towing, 258
Storm soaring, 201
" Starkenburg," the, 114
Streamline bodies, 30
Strength regulations, R.R.G., 5
requirements, 3
Strut-end fittings, 151
Strut, vertical, fuselage, 74
Struts, bulkhead, 75
lift, 60, 68–70
lift, construction of, 135
position of, 25
spruce, limiting stress, 263
steel, limiting stress, 263
Support reactions, 46–47

TAIL area, 31
load, 6–10
loadings, 81
plane and elevator spars, 83
planes, factors of loading, 4, 5, 8
skid, 37, 80, 141
unit, 142–144
unit fittings, 153–155
unit types, 81
Tailless sailplanes, 95–98
Taking-off, 182
and climbing (towed flight), 209
main plane loading, 181
Tapered wings, 20–21, 41, 43, 47
Terminal velocity dive, 6–11
" Tern," the, 121
Torsion and bending, 57
Torsion device, 53
maximum, 8
resistance to, 57
Torsion tube, 51, 52, 63
Towed flight, aerodynamic forces, 210
sailplane, 208
Towing, aero- and auto-, 207–217
aeroplane and apparatus, 207
Tailing-edge, construction of, 131
Turning, 185

VARIOMETER, 220
Varnish, 135

WALKER, Sir Gilbert, 203
Wash-in, 23
Wash-out, 23
Weight, fuselage, 15
wing, 14, 21
Weights of main units, 14–16
" Westpreussen," the, 114
Wheel chassis, 80
" Wien," the, 113
Wind roses, 172
Winds, direction and velocity, 171
Wing, centre of gravity, 33
loading, 16
position, 32–34
weight, 14, 21
Wing-tip, construction of, 132
effect, 40, 48
Wings, braced or cantilever, 23
oscillation of, 24
tapered, 20–21, 41, 43, 47
Wire rope, steel, for towing, 258
Wires, 167
high tensile steel, table, 259
streamline and swaged, sizes and strengths, 258

THE LONDON AND NORWICH PRESS, LIMITED, ST. GILES WORKS, NORWICH